# PHYSICAL BASIS OF GEOGRAPHY

*by*

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# PREFACE

The object of writing this book is to place in the hands of the advanced Indian students a suitable text-book covering the whole field of physical geography. A thorough grasp of physical geography is essential to any advanced study in geography. It is, however, a matter of regret that books on physical geography written for High School classes in England are being recommended to advanced students of geography in India as being sufficient for their needs. Apart from the elementary treatment of the subject in these books, the examples given are necessarily foreign. To remove this want the present book is written by an Indian, appreciating fully the difficulties of Indian students. In spite of the ambitious scope of the book, the author feels confident that the student will find in it all that he needs for the examination and much more than in any one book he may be using at present. This is being emphasised here, because there is a tendency in certain quarters in India to despise books written by Indian authors on geography.

The material for this book has been collected not only from standard works on physical geography, but also from a number of articles published in different magazines. The sources have generally been thankfully acknowledged in the body of the book. The author is specially indebted, however, to Traite de Geographie Physique by Prof. de Martonne, who was at one time his teacher, and Gruendsuge der Physischen Erdkunde by Obst and Supan.

The arrangement of the subject-matter is original and is not to be found in any book that the author has seen so far. The object underlying this arrangement is to maintain the continuity of the subject. Following the Continental geographers, atmosphere has been studied first and lithosphere afterwards. It will be seen that the atmosphere affects fundamentally, through climate, the landforms and other forms on the earth's surface. The effect of lithosphere on atmosphere is negligible, if at all. The greater importance of the atmosphere, therefore, justifies its being discussed first.

*...iversity of Allahabad,*
*March 1942*

UBEY

## PREFACE TO THE SECOND EDITION

The demand for second edition of this book shows that it fills the need for a suitable book on Physical Geo graphy. A few changes have been made here and there. The size of the book has also been changed owing to the difficulty of getting the required type of paper.

*December, 1945.* R. DUBEY

## PREFACE TO THE THIRD EDITION

The author takes advantage of this opportunity to add further to the material given in this book. This will enhance the usefulness of the book for the students.

*January, 1948.* R. DUBEY

## PREFACE TO THE FOURTH

The book has been brought uptodate and much useful material has been added to enhance the usefulness of the book.

*August 15, 1952.* R. DUBEY

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# INTRODUCTION

IMPORTANCE OF PHYSICAL GEOGRAPHY—PHYSICAL ENVIRONMENT —CULTURAL ENVIRONMENT—DUAL ASPECT OF GEOGRAPHY.

The aim of Geography is to study the surface of the earth in relation to man. Man's material progress depends partly on the *resources* of that part of the earth's surface which he inhabits, and partly on the *will* which he has acquired from his ancestors. Man wills his actions, but in order to be successful he must take into consideration the stage that has been set for him by nature. This stage is the *physical environment* which he cannot escape. It is true that man has mobility and can migrate from one type of environment to another. But wherever he goes, he must obey or 'co-operate' with the laws of Nature of one sort or the other. In the early stages, the savage man was largely at the mercy of his physical environment. But as his understanding of the working of nature increased, he began to make an effective use of the materials and natural forces existing around him. He began, therefore, to acquire a certain amount of control over his environment.

Different groups of people occupied different parts of the world with differing environment. These groups adjusted themselves to their environment or gained control over it according to their experience. During this process of adjustment there was Natural Selection in which were weeded out the unfit and the unadaptable, only the most adaptable surviving. This is called the survival of the fittest. Different types of human civilisations, thus, slowly evolved on the surface of the earth. The development of these civilisations created, therefore, the material or *cultural environment*, which is the expression of Man's accumulated experience and achievement. Conscious and planned use of Nature's gifts resulting in agriculture, industry, towns and communications is comprised in cultural environment.

Man now finds himself between two environments, the physical environment and the cultural environment. The one is the creation of nature, while the other is the creation of his own will. Physical environment offers him stimuli of various kinds and of different degrees. The cold, or other elements of nature, compels him to provide himself with clothes or to seek shelter. To satisfy his wants he must work. He must work to get a shelter, or to get food or drink. His work is easy or difficult according to his physical environment. There are some parts of the earth's surface where one can gather food or drink without much effort. There are other parts where this effort is very great. Physical environment also

affects man's health and, therefore, his energy and capacity for work. The effect on health will thus determine the effectiveness of man's effort in satisfying his wants.

Under the influence of the stimuli provided by physical environment, or as a result of the efforts man makes for satisfying his wants, the material or cultural environment is created. Land is cultivated, irrigation is provided, industries develop, rivers are bridged, roads and railways are built, towns grow and there is the whole paraphernalia of modern civilisation that is born simply out of man's efforts for satisfying his wants.

It is true that most of the elements of physical environment are capable of only slight modifications by man. Nevertheless, even this slight control that he has over nature means a great deal towards his progress. For example, man knows very little about the atmosphere and can control atmospheric conditions even less. But he has studied some of the laws that apply to it. He has studied how the birds fly into the air with the help of their wings. He has been able to invent, therefore, his flying machine with the help of which he is able to achieve so much. Man's material progress is largely determined by his success in adjusting his actions to his physical environment. According to Reed "Human achievement is not consummated by defying and conquering the forces or laws of nature. Invariably it is won by understanding and utilising those laws."[1]

Man's physical environment consists of air, water, land and organic life. These are described as atmosphere, hydrosphere, lithosphere and biosphere respectively. All these 'spheres' are subject to certain laws of nature which are always in operation. These inexorable laws of nature keep the whole physical environment in perpetual change. There is no stagnation in nature. The atmosphere is constantly changing from one state to the other and thus gives us our weather. Hydrosphere is subject to constant motion and change of form. Currents, waves and tides keep it on the move ; evaporation, condensation, and freezing change its form to vapour, clouds, rain, snow and ice. Lithosphere is also constantly changing, though its changes commonly pass unnoticed. New lands are forming, while the old ones are being destroyed. Erosion here, deposition there ; one coast emerging, another submerging ; all these are the various phases of the change that characterises lithosphere. The change in the biosphere is, of course, the most noticeable. Life and decay are the two most important characteristics of all organisms. Birth, growth and death are the rule for everything biological on the surface of the earth. The forces or laws of nature go on doing their work irrespective of what use man may or may not make of them.

The forces of nature make our weather and climate which have such a far-reaching influence on our life. They make our plains, plateaus and mountains which determine our habitat and control our movement. They make our soil; they deposit our coal and concentrate petroleum; they collect the metals into ores; and they determine the nature of the flora and fauna on the earth's surface. In other words, the earth's resources are born through these forces of nature.

Geography studies, therefore, the physical as well as the material environment on the earth's surface as affecting man's development. The two environments cannot be separated in this study. Geography has to study not only the *distribution* of natural phenomena (including all forms of life) on the earth's surface, but also how this distribution has been utilized by man for his material progress. It is not the object of the geographer to usurp the function of the specialist in sciences, but for the proper understanding of the *surface distribution* of phenomena (which is the geographer's special scope it is necessary to know how the phenomena are caused.)

This dual aspect of the study of geography has been marked ever since its development under the Greeks. Under the Greeks, geography was divided under :—(*a*) cosmography and (*b*) chorography. Cosmography dealt with physical phenomena, while chorography described the known lands. This description of the lands included the description of the relief as well as the people and their customs. There was, however, no attempt made to correlate the two branches of study, cosmography and chorography.

It was not until the 19th century that this correlation was attempted and the study of geography made scientific; *i.e.*, seeking explanations for facts observed. But a scientific study of geography is possible only through a thorough grounding in Physical Geography. For the very basis of geography lies in physical environment. It is Physical Geography, therefore, which studies this environment that can provide explanations.

The study of geography, like all other sciences today, has been marked in recent times by a great deal of specialization. The specialist in his zeal for specialization is, however, apt to forget the physical basis of geography. It is, therefore, good to remind him that his specialized study cannot be separated from the foundation, the *Physical Basis of Geography.*

CHAPTER I

# THE EARTH

SOLAR SYSTEM—ORIGIN—NEBULAR HYPOTHESIS—PLANETESIMAL HYPOTHESIS—TIDAL HYPOTHESIS—INTERIOR OF THE EARTH—CONTINENTS AND OCEAN BASINS—TETRAHEDRAL THEORY—SUESS'S THEORY—RADIO ACTIVITY THEORY—WEGENER'S DRIFT THEORY.

## Solar System

The earth is a planet which, like its sister planets, revolves round the sun and thus gets the solar energy necessary for maintaining life on it. You see at night myriads of shining bodies. Some of these are, like our Sun, stars; others like our earth, the planets which revolve round the Sun. They, however, appear all alike to us, shining. Our earth itself must appear as a shining body to people, if there are any people there, on those heavenly bodies which appear to us lighted at night. A careful observation of the skies at night will reveal that the shining heavenly bodies may be divided into two general classes :—(i) those that *give out* light and (ii) those that *reflect* the light given out by other bodies. Those that give out light are called 'stars' and those that reflect the light are called 'planets.'

Astronomers tell us that there are some stars that have a retinue of planets which revolve round it. The planets are, in fact, the 'family' of the stars. The star and its family, the planets, are called the Solar System. The universe contains several solar systems. But we know very little about them. Indeed, our knowledge even about our own solar system is limited.

What we call "*universe*" h s a number of galaxies. It is believed that there are more than 100 million galaxies (nebulae) in space. One of these is Milky Way Galaxy. In it are perhaps 5000 million stars including all that we can see in the sky; and great clouds of dust and gas. About two-thirds the way from the centre in the Milky way is a yellowish star which is our sun. Our tiny earth circles round it and, at the same time moves on through space with the galaxy as a whole which is slowly turning like a wheel.

The bright pathway across the sky at night that we call Milky Way is really the concentrated light of all the stars between the earth and the other rim of this great wheel.

## Origin

The origin of these solar systems is a great mystery. In comparison with the vastness and complexity of the Universe, man's

life is short and his means to solve this mystery limited. It has, therefore, been possible only to conjecture about the origin of our solar system.

During the 19th century various hypotheses were advanced about the origin of the earth and the solar system generally. These hypotheses may be grouped into two general classes :—

(a) *Monistic Hypotheses* ; that is to say, those hypotheses which believed that only one mass or body was involved in the creation of the solar system.

(b) *Dualistic Hypotheses*, that is to say, those hypotheses according to which two separate masses or bodies were involved in this creation.

Fig. 1. Spiral Nebula

Representative of the monistic hypotheses is the '*Nebular Hypothesis*' advocated by Kant[1] and Laplace[2]. According to this hypothesis, the solar system resulted from a 'nebula' or a gaseous mass that was rotating. Gradually, owing to this rotation, the gaseous mass began to cool down and shrink in volume. This shrinking increased to speed of rotation, and a stage came when the speed of the equatorial belt of this nebula was so great that an equatorial ring was left behind, while the main body continued to shrink.

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1 Immanuel Kant was a Professor at the University of Kœnigsberg in Germany. He propounded this hypothesis in 1755.

2 Kant's hypothesis was elaborated and given finishing touches in 1789 by a French scientist of Paris, Pierre Simon Marquis de Laplace.

This process went on until nine such rings were formed. Each of these rings later formed a rotating sphere which revolved around the central mass. The remaining part of the original gaseous mass is the present sun, and the rings are the planets.

Each of the rings formed from the gaseous mass developed into planets and repeated the original process, which resulted in these planets having a ring around themselves. These later rings formed the satellites or the moons belonging to the various planets.

This hypothesis is simple to understand, but cannot stand a searching scrutiny in the light of the present knowledge of the earth. William Hobbs, an American geologist says, in fact, that this hypothesis is responsible for fastening upon us not only a false conception of the nature of our planet, but an erroneous notion of the origin of the lava as well.[3]

Under the dualistic hypotheses comes Chamberlin's *Planetesimal Hypothesis*. In 1905. T. C. Chamberlin put forth his hypothesis according to which the solar system has been formed from the aggregation of the wreckage that resulted from the close approach of two great stars. An evidence of such a wreckage can be seen in the 'Spiral nebulæ' that are seen in the sky. These spiral nebulae are assemblages of stars and nebulous matter of immense size.

The wrecked material ultimately grouped itself into a few bodies which are called the planets. During this process of grouping together, the various parts of the wreckage collided and produced immense heat.

It must be noted that while the nebular hypothesis bases the origin of the solar system on a heated gaseous mass, the planetesimal hypothesis bases it on a cooled matter.

Another and solid hypothesis, also belonging to the dualistic class, is James Jeans' '*Tidal Hypothesis.*' This is a very recent hypothesis, but has already gathered a considerable number of supporters.

The essence of the tidal hypothesis is that in the distant past a big star approached our Sun so very near that it raised tides in it. Just as the moon, by its nearness to the earth, raises tides in the oceans, in the same way this enormous star, because of its nearness, raised tides in the fiery atmosphere of our Sun. These tides gradually became so great that just under that approaching star they attained a height of several thousand miles. The height went on increasing with the still nearer approach of the star, until finally, the gravitational force of the approaching star exceeded that of the sun and the top of the tidal matter shot off towards it. Later, a whole stream of gaseous matter shot out from the sun to meet the approaching star.

3W. H. Hobbs: *Earth Evolution and its Facial Expression*; 1922, page 2.

Our sun, however, did not lie on the direct path of the approaching star which, therefore, passed on.[4] As this star receded farther and farther from the sun, its gravitational pull diminished and no more matter went out from the sun. The matter that had already left the sun formed a long filament of gaseous matter which was set into motion by the gravitational pull of the receding star. Owing to the law of gravitation, this matter could not fall back into the sun, but described orbits round it. As time passed, the gaseous matter cooled down and formed the various planets.

On the same principle, the moons belonging to the various planets were also formed. As the gaseous matter began to revolve round the sun, tides were formed when this matter approached too near the sun resulting in the breaking off of some of the matter. This broken off matter ultimately became the moons of the planets.

Facts in support of Jeans' theory are :—

(*a*) Astronomical facts about the various parts of the solar system ;

(*b*) Geological facts concerning the age of the oldest stones of the earth ;

(*c*) Investigations into the age of meteorities.

They all invariably point to the age that Jeans has supposed for the earth.

Facts that enhance the probability of Jeans' theory are :—

(1) Magnitude of the various planets[5].

[Starting from the sun, we come to the small planet (1) *Mercury*, then (2) *Venus*, a little larger ; (3) *Earth*, about same size, (4) *Mars*, which is smaller and does not fit properly into the scheme, then (5) *Jupiter*, and (6) *Saturn*, the giants, then (7) *Uranus*, and (8) *Neptune*, considerably smaller again, and finally the small planet, (9) *Pluto*].

4 Jeffereys, however, now believes that there must have been a collision, though not with the Sun, but with its companion star. Many mathematical difficulties about the rotation of the planets which make it hard to accept Jeans' hypothesis, are solved if we accept Jeffereys' view and that the Sun was a double star.

5

| I Planet | | II Diameter (Miles) | III Distance to Sun (Million Miles) | IV Time taken to revolve round the Sun |
|---|---|---|---|---|
| 1. Mercury | ... | 3000 | 36 | 88 days |
| 2. Venus | ... | 7800 | 67 | 224 1/2 days |
| 3. Earth | ... | 7922 | 93 | 365 1/4 days |
| 4. Mars | ... | 4200 | 141 | 687 days |
| 5. Jupiter | ... | 87000 | 483 | 12 years |
| 6. Saturn | ... | 74000 | 886 | 29 1/2 years |
| 7. Uranus | ... | 31000 | 1800 | 84 years |
| 8. Neptune | ... | 33000 | 2800 | 164 1/2 years |
| 9. Pluto | ... | 3000 | 3700 | 248 years |

With the exception of Mars, they all fit well into the cigar shape which, according to Jeans, the solar matter ejected by the sun must have possessed. For the ejected matter from our sun must have been in proportion to the gravitational pull exercised by the approaching star. This pull would be the least while the star is approaching or receding and the greatest when it is very near.

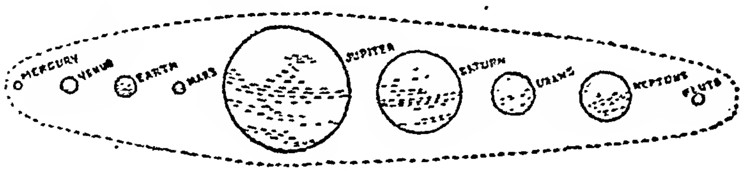


Fig. 2. Cigar-shaped Solar System

Jean's theory had been fully formulated before the discovery of Pluto.* The fact that Pluto is so small enhanced the popularity of the tidal hypothesis.

(2) Position and shape of the orbits.

The mean orbital plane of the planets does not coincide with the rotational plane of the Sun, but is at an angle to it.[6] This is in accordance with the tidal hypothesis. For here we see the influence of the orbital plane of the paternal sun, which caused this inclination.

(3) Satellities of the planets ; their size and distribution bear out the tidal hypothesis.

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*The discovery of Pluto in 1930 followed a prediction made in 1915 by Lowell, the founder of the Lowell observatory in U. S. A. Lowell had noticed some discrepancy between the theoretical and observed positions of the two outer planets, Uranus and Neptune. He explained this discrepancy by the attraction exerted by another planet that was still unknown then.

Lowell had mentioned in his prediction that to explain the discrepancy, the new planet must be about six or seven times longer than the earth and must be quite bright to exert the necessary perturbations in the positions of the other planets. The completion of the new 200-inch telescope on Palomar Mountain in California has now enabled Dr. Kuiper to make a detailed study of Pluto. His measurements give the diameter of Pluto as 3650 miles, or only about one-half of that of the earth. The mass is estimated to be less than one-tenth of that of the Earth. The discovery of Pluto therefore does not solve the problem that faced Lowell and the search for the wanted planet is going on. Meanwhile Pluto can only be regarded as the wrong object found in the right place.

6The inclinations for the various planets are as follows :
Mercury 7°
Venus 3 1/2°
Mars 2°
Jupiter 1°
Saturn 2 1/2°
Uranus 1°
Neptune 2°
Pluto 17°

There is a great similarity between the system of planets with their moons and that of the sun with the planets. Satellite systems are in many respects *miniature planetary systems*. In the case of planets which have many satellites, generally the middle satellites are the largest, the outermost and innermost satellites the smallest. This is also the case with the planets of the solar system. This indicates that there must have been some similarity between the causes that led to the formation of the planetary system and those of the satellites.

According to the tidal hypothesis, the large planets, which remained in the geaseous state longest, should have a large number of comparatively small satellites. The smaller planets should have a small number of satellites of a comparatively large size; while the smaller planets should be without satellites. This is what is in nature. Jupiter and Saturn, the biggest planets, have a large number of comparatively small satellites; Mars has two small ones; the Earth has one; while Venus and Mercury have none.

The only planet that does not really fit into this scheme is Mars. Considering its place in the solar system it ought to be larger than it is, as is also shown by its satellites. It is surmised, therefore, that originally Mars must have been larger than it is now.

Recently a revolutionary theory has been developed at Cambridge.

The theory has been developed by F. Hoyle and R. A. Lyttleton of Cambridge (Hoyle—The Nature of the Universe). It is a theory to explain the whole of the universe. There are two facts. The stars are mostly hydrogen. They derive their energy by the conversion of hydrogen into helium. A third point is that the major part of the matter in the universe is not the stars but in the space between them. Stars are only condensations from inter stellar gas. When a star gathers an excess of interstellar material it begins to burn at a very high rate, and at the same time it begins to contract and rotate very fast. Finally a stage comes when the star explodes and its outer layers fly off as incandescent gas. Such an explosion is a supernova. Hoyle and Lyttleton believe that the planets came from a supernova. Two facts show that the planets were never part of the sun. First, the planets are formed mostly of heavy elements while the sun is composed mainly of hydrogen and helium, which are very light. Second, the planets are revolving rapidly at a great distance from a *slowly turning* sun. It is pointed out that about half the stars known are members of "binary systems," *i. e.*, two stars revolving round a common centre. Similarly the sun was at one time part of a "binary system." When the companion of our sun blew up as a supernova the hot gas emitted during the explosion was captured by the sun, and formed a revolving disc round it. It is this gase-

ous disc which gathered into planets. It is natural, says Hoyle, that the planets be made of heavy elements not of hydrogen and helium, like the sun because the supernova has been contracting and thus increase in density before the explosion occurred.

## Interior of the earth

There had been many conceptions of the earth's construction. Influenced by the Kont-Laplace Theory of the solar system, the earth was pictured as an enormous molten liquid ball covered with a fairly thin solid crust. It has been established more or less accurately that the average increase of temperature is one degree centigrade for about every 38 yards of depth. This discovery was one of the most important discoveries, not because of its practical use in tracing minerals but because of the important conclusions to which it led. In the first place it supplied proof that the earth itself must possess a source of heat, because the heat of the sun only penetrates to a very small depth. Still more important is the simple calculation that if the temperature actually increases one degree in every 38 yards we reach a temperature of over 3,000° at a depth of about 62 miles. At such a temperature no rock can remain solid, and so it was concluded that the solid crust of the earth cannot be thicker than 62 miles anywhere. As the earth's radius is about 7926 miles the globe is like an apple with a very thin skin.

In this calculation, based on the assumption that temperature also increases in the same ratio at greater depths, an important factor—pressure has not been considered. The melting point of a substance rises with increased pressure, *i. e.*, under pressure a substance only becomes liquid at a higher temperature. Many scientists, therefore, now believe in a solid, rigid earth core.

A third set of scientists led by Zoeppritz and Ritter declared that the earth's core was gaseous. This theory was, however, soon discarded. There are, therefore, only two theories in the field today—liquid core and solid core.

Laplace's liquid core is hard to reconcile with the high pressure in the earth's interior. But the volcanoes prove that there must be liquid rock under the solid earth's crust. A compromise was reached which suggests that at a depth of 37 to 62 miles the earth is liquid.

Various considerations led to the conclusion that at a deeper level the liquid layer (the Pyrosphere) must pass into a central core with quite different properties, the so-called barysphere. The statistics of the density of the earth endorse this. The average density of all known rocks in the earth's crust amounts to 25, *i. e*, rocks are two and a half times heavier than water. The density of the entire earth, however, is calculated at 5·5. It follows that much heavier masses must be accumulated in the earth's interior than on the sur-

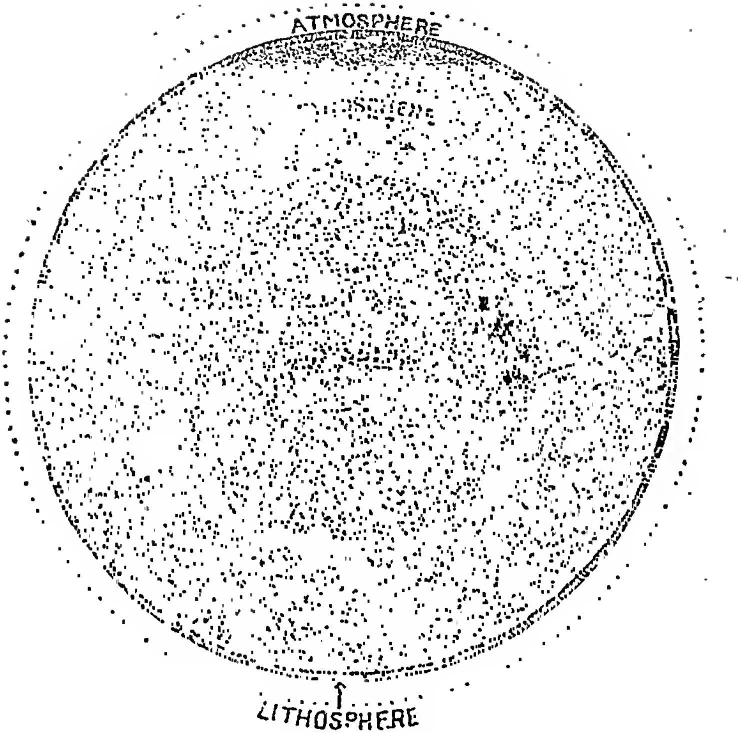


Fig. 3. Structure of the earth

Depth of Lithosphere upto 62 miles.
,, Pyrosphere from 62 to 1,8000 miles
,, Barysphere below 1,100 miles.

face. The high density of the earth as a whole can be explained if the barysphere has a higher specific gravity than iron.

This is supported by the study of earthquakes. Comparison of seismographic records reveals important facts concerning the transmission and velocity of earthquake waves.

It was first discovered that all the waves travelling along the surface have a similar velocity, whilst the waves finding their way through deeper parts of the earth are transmitted with different velocities. The velocity increases regularly to a depth of about 1,800 miles, but at greater depths it remains unchanged. That is, somewhere around a depth of about 1,800 miles, there must be a break between two different zones. The upper one has variable proper

ties, the lower is homogeneous, at least in the transmission of earthquake waves. This gives the first indication of the measurements of the barysphere, whose upper limit must be set at a depth of about 1,800 miles.

According to the newest conceptions, the earth's core is considered to be a viscous mass in an intensely compressed condition, reacting to active forces like a solid.

## Continents and ocean basins

The outer crust of the earth is divided into continents and ocean basins. The origin and nature of these have aroused as much controversy as the origin of the earth itself. The more important of the hypotheses concerning the origin of continents and ocean basins are given here. Geologists agree that the material of which the ocean basins are made differs from that of which the continents are made.

The continuous cooling from a gaseous state has given our earth its present face. Geologists, therefore, draw the simile from the molten matter in the iron furnace in explaining the structure of the earth.

In the iron furnace the heaviest material lies near the bottom, a little lighter material above it and the lightest material at the top. Suess has named the heaviest layer—barysphere—*nife*, made up of the initial letters of the two chief constituents of barysphere, nickel and ferrum (iron.) The lighter layer is called *Sima*, from silicon and magnesium : and the lightest or the topmost layer is known as *sial*, from silicon and aluminium.

The continents which are the uppermost layer of the earth are made up, therefore, of the lightest material, sial ; while the ocean basins are made up of the sima which is heavier than the sial. According to Wegener, another geologist, sial forms the continents, while sima forms the ocean-bed and continues under the continents.

## Teatrahedral Theory

The most suggestive of the hypotheses about the origin of the continents was the Tetrahedral theory of Lowthian Green, who assumed that the earth being a slowly cooling mass, its interior is contracting more rapidly than its outer crust, and therefore, under the influence of the force of gravity, the outer crust collapses.

Fairbairn, in order to test this theory, carried out experiments on the crushing of wrought-iron tubes. These experiments led him to believe that the collapsing sphere will tend to approach a tetrahedral form. Tetrahedron is a three-dimensional body contained by four equal triangles. The following diagram shows a tetrahedron :—

Fairbairn concluded that the corners of the tetrahedron that the outer crust of the spherical earth will form will rise above the water, forming triangular masses of land ; the faces of the tetrahedron will remain covered and will form the oceans. He places one corner of such a tetrahedron at the south pole and the other three corners in the northern hemisphere. The corner at the south pole is the Antarctica and the opposite face of the tetrahedron is covered by the

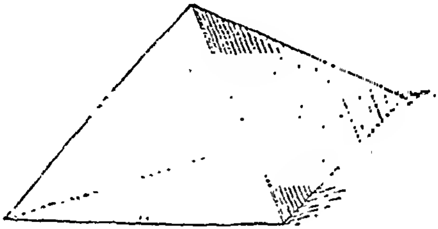

Fig. 4. A Tetrahedron

Arctic Ocean. The triangular masses of land formed by the other three corners are represented respectively by North and South America ; Europe and Africa ; and Asia and Australia. All of these land masses are wide towards the north and tapering towards the south. Between these three land masses lie the Atlantic, the Indian and the Pacific Oceans. All these oceans narrow towards the north ; and, the south, where the tetrahedral ledges are the lowest, they unite into a continuous belt around the globe.

Lowthian Green's theory was favourably received in France, where De Lapparent was the first to recognize it as a probable hypothesis. Since the close of the last century it has been accepted by many writers in England, Germany and the United States as well.

The theory is, however, now being discredited on physical grounds. An objection has been raised that the tetrahedron is not a figure of equilibrium for a rotating earth, and even a slight approximation to this form cannot be retained.

### Suess's theory

Suess divides the earth's crust into two parts :

(*a*) resistant part, and

(*b*) non-resistant.

The resistant part comprises of old beds which lie horizontal. Here the crust of the earth has been rigid. It has broken but it has never crumpled. In the northern hemisphere there are three areas in which such beds lie. These are :—

(*i*) Laurentia (includes most of Canada east of the Rockies and the western islands of Scotland); (*ii*) the Baltic Shields; and (*iii*) Angaraland (includes eastern Siberia); (*iv*) the Gondwanaland (including the greater part of South America, most of Africa, Arabia, Syria and the Peninsular India).

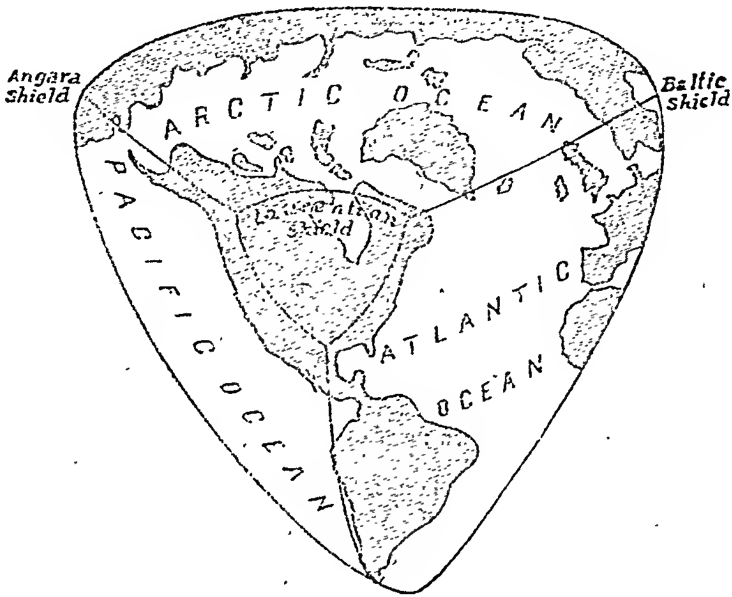


Fig. 5. Tetrahedral Shape of Continents

Between these areas lie non-resistant beds which are often folded. The crust here has been weaker and has yielded to tangential pressures by crumpling and overthrusting. The crumpling was not a continuous process. There were well-defined periods of folding separated by intervals during which the whole earth was free, or almost free, from such disturbances.

During these intervals, however, fracturing of the resistant areas took place and large blocks of the crust sank. Where these blocks sank the place was covered by the oceans; besides, there were also other extensions of the sea over the land. When the Laurentia and the Gondwanaland broke up, large portions sank down and were covered by the sea. Thus, the present Atlantic came into existence.

The non-resistant crust covered by the old sea of Tethys (of which the Mediterranean Sea is a remanant now) lying between the resistant

masses of the north and the south was crushed and the series of fold mountains in Asia and Europe were thus created.

According to Suess, therefore, the resistant crust and those parts of the non-resistant crust which have been upthrust due to folding form the continents. The oceans, on the other hand, occupy the non-resistant parts of the crust and those parts of the resistants crust where faulted blocks have sunk.

### Radio-activity theory of Joly

Like Wegener, Joly thinks that the continents are sheets of sial floating on the sima. The sial and the sima are both radio-active and thus heat is being continuously generated. Unless this heat can escape, the temperature must rise.

It is known that the melting point of sial is much higher than that of the sima, which is basaltic in nature. If at a certain period the whole of the sial is solid and the sima is also solid down to a considerable depth, heat can only escape by the slow process of conduction. Beneath the sial there will be no escape from the sima, because the base of the sial itself, owing to its own radio-activity, must be nearly at the melting point of sima. Since the escape of heat is so slow the temperature rises and the sima melts from below upwards.

The tidal movements in the molten sima acting upon the downward projections of the sial move the whole crust so that the local accumulations of heat originally formed beneath the sial come to lie under the thin layer of solid sima. This is quickly thinned still further, and molten sima escapes through fractures. The loss of heat now becomes more rapid and an era of cooling and consolidation begins.

It has been shown by experiments that as the sima melts it expands, and therefore, the general level of the earth's surface is raised. But because the density of the sima is decreased by expansion the masses of sial which are floating in it sink more deeply into the layer, and relatively to the surface on the sima they are depressed. As the sima cools again and becomes denser the surface falls, but the sial masses rise relatively to the sima.

The sima, however, continues to contract further and the covering of sial becomes too large. Then begins the period of folding and other earth movements to enable the crust to descend with the sima.

### Wegener's theory of continental drift

In view of the fact that the mountain building must imply the closer approach of the regions on either side of a crumpled belt, it si not surprising that a conception of continental movement has com-

menced itself to some geologists. Although, however, various suggestions have been made regarding extensive modifications in the positions of the continents, it is only within comparatively recent years that a hypothesis has been worked out in detail. This was the work of Alfred Wegener, a German scientist (1880-1930). He suggested that the mass of sial forming the continents can be regarded as being not only supported but floating in the denser sima.

According to Wegener's hypothesis the continents in some old geological times were all closely joined together in one great area which he named 'Pangaea.' Parts of this area were from time to time covered by shallow seas, while the greater part of the earth was occupied by a continuous deep ocean.

Wegener believed that at a later stage Australia and Antarctica became separated from southern India and Africa, the distance between them increasing slowly as they drifted apart. At a later stage the Americas moved westwards away from Europe and Africa with which they had been previously joined.

The continental drift cannot as yet be accepted as a *fact* beyond all doubt. Unfortunately, a discovery recently annouuced makes the Joly hypothesis highly improbable and certainly unusable for the purpose of the continental drift. It has been found, in contradiction of long-standing assumption, that granite melts at a distinctly lower temperature than basalt. (Bull. Geol. Soc. of America, Vol. 40. No. 1, 1929).

Among the objections to the drift theory may be mentioned :—

the imperfect fit of continental margins supposed to have been joined before rifting in the Cretaceous,

the pre-Cretaceous faunas on opposite sides of the Atlantic ought to be identical, instead of having only a few similar forms in common,

the low tensile strength of rocks and urges that the Americas would have been torn to garments in their supposed journey across the Atlantic.

All the continents have been deformed along their present margin throughout geologic time.

"Cape Foldings" of South Africa do not end abruptly, as shown by some of the protagonists of the theory, to join with South America. The Cape folds extend westward in the Langeberg, bend gradually north-westward, and die out against broad folds that trend north-northwest. Between this salient and the west coast the Paleozoic sediments are disturbed only by gentle folding parallel to the coast—the east-west structure does not carry through. Whatever the bearing may be on the drift hypothesis, the Cape Ranges have not been broken off sharply

at the coast and cannot by any stretch of imagination be represented as having a simple structural relation to the transverse fold of Argentina.

The arguments in support of this hypothesis are :—

(1) The similarity of shape of the two margins of the Atlantic Ocean. This similarity had been commented on for many years before Wegener's hypothesis. It has been remarked, for example, that the 'bulge' on the east of South America (Brazil) would approximately fit into the 'gap' in the west of Africa (the Gulf of Guinea), and that if North America and Greenland are brought up against Europe, a fairly complete junction can be made. It is, of course, necessary in considering the boundaries to take the boundary of the continental platforms covered by the shallow seas.

(2) The geological structure on the two sides of the Atlantic is similar. Attention may be best directed to the mountain systems in Europe, Africa and America. The arrangement of the folded mountains in these continents is striking. The Caledonian and Armorican folded mountain systems of Europe can be traced into the eastern part of North America.

The geological structures of the southern hemisphere afford similar evidence. The mountain systems which nearly meet in the estuary of the Plate River in South America may be regarded as actually meeting and crossing near Capetown. The diamond deposits (which require peculiar conditions for their production) are known both in South Africa and South America.

(3) The evidence of ancient faunas and floras of the two sides of the Atlantic, derived from the fossils obtained in both areas, also supports the former association of the two masses.

The fossil plants which characterize the carboniferous rocks of the two areas belong precisely to the same species and occur in similar succession in the rocks, one flora replacing another, time after time, giving the same order of plant species in the north-western Europe and parts of the U.S.A.

(4) Great differences registered by distance measurements in 1823, 1870 and 1917 seem to show that Greenland is approaching North America at present at a rate of about 35 yards annually.

(3) Extraordinary migrations of some living animals. Certain forest rats or lemmings, of north Scandinavia appear to increase greatly in numbers at certain periods. At intervals of from ten to fifteen years an increase in population of lemmings is followed by an astonishing movement towards the west, the lemmings crossing the land for miles until they reach the western shore when they plunge into the sea and eventually die. This surprising migration is regarded by some as connected with an effort to reach a land which is now no

longer there; it is supposed that the ancestors of these creatures formerly had periodical migrations to some western land and that the tendency to swim in that direction has been inherited.

Wegener's hypothesis helps to explain the distribution of animals both now and in the past, and makes very much easier the explanation of changes in past climates.

There are many arguments that its critics advance against Wegener's hypothesis. The most important being:—

(1) The geo-physicists hold that there is no known force which is capable of moving these continental masses in the substratum of sima which supports them. If such a force existed, it would stop the rotation of the earth within a year.

In the search for a force capable of moving continents several suggestions have been put forward. The possibility that radio activity may have led to periodical excesses of heat and so to a greater fluidity of the sima has been borne in mind. It has also been suggested that pos ible convection currents in the sima may at times have provided a means for the moving of the continents.

CHAPTER II

# PLANETARY RELATIONS

EARTH AS A PLANET—ROTATION—FOUCAULT'S TEST OF ROTATION—OTHER TESTS—COPERNICUS SYSTEM—PTOLEMAIC SYSTEM—ROTATION AND TIME—UNIVERSAL TIME—DATE LINE—EQUATION OF TIME—REVOLUTION ROUND THE SUN—PRECESSION OF EQUINOXES.

The earth is a planet revolving round the sun. It is not a complete sphere (a sphere is defined as a body with evenly curved endless surface, all points of which are equidistant from the centre), but a spheroid or a geoid, *i.e.*, an irregular sphere formed by rotation on its axis. Because of its rotation it is slightly flattened at the poles, and therefore, the equatorial and the polar diameters are different. The equatorial diameter is 7926·6 miles, while the polar diameter is 7899·9 miles; or 24·7 miles shorter. The earth's rotation has not only flattened it at the poles but has also given a 'bulge' at the equator. The equatorial circumference, is 24,902 miles, while the meridianal circumference, or circumference through the poles, is 24,860 miles; 42 miles shorter.

The total surface area of the earth is 196,950,000, sq. miles (roughly 197 million) of which 139,440,000 sq. miles is water and 57,510,000 sq. miles land.

We notice that the rotation of the earth on its axis is an important fact which has given it its shape and fundamentally affects the life on its surface. The earth was set to rotate by the gravitational forces of the sun and the other star whose approach led to the birth of the solar system. The speed at which the earth rotates is tremendous. It is about 1,041 miles per hour at the equator or about 18 miles per minute. Compare this with the speed of the fastest train in India, the Punjab Mail running about 50 miles per hour; or with the fastest aeroplane in the world doing about 600 miles per hour.

The rotational speed is the greatest at the equator where the circumference is the greatest. Away from the equator towards the poles the circumference decreases, but the time of the rotation is the same as at a equator, *i.e.*, about 24 hours. The speed there is consequently less, until at the poles there is no motion. Allahabad is rotating at a speed of about 945 miles per hour; or about 15½ miles per minute.

In spite of this tremendous speed, we are unconscious of the earth's motion. This is because it moves along at a constant speed, without shocks or vibration. We are unable to perceive that motion,

unless there is something else that does not move with us. If we travel in a train at night, with the windows shut, we are aware of the motion of the train only because our bodies are inclined to move backwards or forwards when the train accelerates or slows down suddenly. But if the movement of the train were perfectly even and if the rails were absolutely smooth, we should not notice that we are moving at all. As long as we do not look out of the windows we have no means of telling in which direction the train is going. This is exactly what happens in the case of the earth. We cannot notice the earth's movement because it is perfectly regular, without bumping or jerking, and because all the objects around us move at exactly the same rate as the earth. The heavenly bodies like the sun, the moon and the stars, however, do not rotate with us. We are, therefore, able to see that we move with reference to those bodies. We see the sun, the moon and the stars moving across the sky everyday from east to west, because the earth moves from west to east on its axis.

It is not, however, easy to convince everybody that the earth is moving and not stationary. The general belief was in the past, as it is even now in India, that the earth was stationary and that all the other heavenly bodies moved around it. With the advance of science, however, this belief became untenable.

There are several ways in which the rotation of the earth can be proved. Some of them are given below :—

### 1. Foucault's pendulum test

This test was carried out by Leon Foucault (1819-68), a French physicist in the Pantheon at Paris in 1851. The principle upon which this test was based is that owing to certain physical laws a pendulum once set vibrating continues to move in exactly the same plane of motion. Foucault tied a long pendulum to the dome of the Pantheon. To the pendulum was attached a fine needle, and underneath was placed a table covered with fine sand. All this apparatus was placed in such a way that the needle attached to the pendulum, when once the latter started to swing, just touched the grains of sand with its fine point and thus traced a slight furrow in the sand. The result was amazing. After not more than a few vibrations of the pendulum the direction of the trace in the sand began to veer. This proved that the earth along with the table had moved. This experiment has been repeated with the same result several times since.

### 2. Things lose weight at the equator

The second direct proof of the rotation of the earth is the effect of centrifugal force at the equator. It can be shown that the same

article weighs less at the equator than at the po'es. This is because the earth is rotating with greater speed at the equator than near or at the poles. This greater velocity causes a centrifugal force to develop which tends to hurl things into space, as happens on the potter's wheel (कुम्हार का चाक) where anything that is not actually on the axis is thrown off the wheel. On the earth, however, the force of gravitation keeps things tied to it. The pull exerted on things by the centrifugal force, however, does tend to weaken the pull of the force of gravitation. This weakening is greater at the equator where the centrifugal force is the greatest than at the poles where this force is the least. Weakening in the pull of gravitation results in the reduction of weight, for *weight is nothing but the gravitational pull towards the centre of the earth.*

Owing to the effect of centrifugal force an object loses at the equator 1/289 of its weight at the poles. An article that weighs two pounds at the poles is about two drachms lighter at the equator owing to the action of centrifugal force. It must be remembered, however, that this loss cannot be detected except on spring balances, because the weights that are used to weigh the article at the equator have themselves lost weight in the same proportion as the article which is to be weighed. The scales will, therefore, show the same weight of the article at the equator as at the poles.

Our weight directly depends upon gravity. If the earth were larger, gravitation would be stronger and our weight greater. On a very large heavenly body like the Jupiter our weight would be terrific, and unless we were much stronger, we should scarcely be able to walk. On a very small heavenly body such as the Mars, we should be able to jump over houses with the greatest of ease.

Therefore, the fact that an article weighs more at the poles than at the equator, taken together with the known figure of the earth, is a proof that the earth does rotate.

### 3. Nothing falls perpendicular

Owing to the rotation of the earth everything on it describes a circle in twenty-four hours round a point of the earth's axis. The farther from the poles, the greater is the circle. The top of a mountain describes a bigger circle in twenty-four hours than its foot, and therefore it rotates faster. The clock tower of the University Senate House at Allahabad describes a bigger circle than the foundation. If, therefore, a ball were to be dropped from the top of the clock tower to the ground below, it will not fall on the point immediately below, but a little to the *east* of it. This is because the tower is moving faster than the point where the ball is to fall.

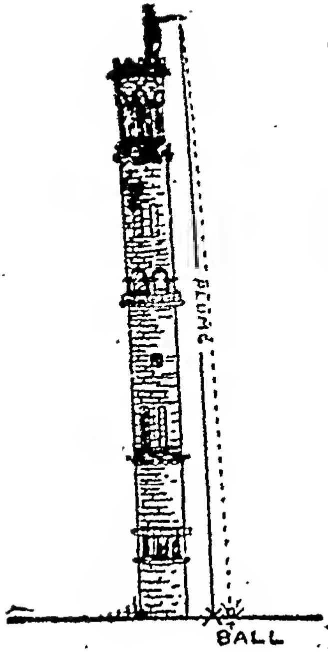


Fig. 6

This can be easily demonstrated. Let a person stand on the tower and lower from there a plumb-line. Down on the ground let somebody fix the point where the plumb-line touches the ground. This must be done with the greatest care. The string of the plumb line must be held straight. Wind or other disturbing factors should be avoided before fixing the point. Then take a ball of lead and hold it exactly at the point from which the plumb-line was lowered. Let go the ball to drop to the ground freely. The ball drops; and it will be found that it has dropped to the *east* of the point previously fixed, for, the earth is rotating from west to east. As the top of the tower is moving faster than the point on the ground, it reaches a point east of the point on the ground before the latter is able to reach it. Before starting out on its downward journey the ball was exactly perpendicular to the point marked on the ground. But for the reason given above, due to greater velocity of the tower, it moved to the *east* more rapidly than this point. Thus, nothing can fall quite perpendicularly to the ground because of the earth's rotation from west to east.

### 4. Pendulum clocks lose time at equator

It is clear that the swinging of the pendulum of a clock is greatly influenced by the force of gravity. The swinging will become quicker if the force of gravitation is greater than if it is less. Under given conditions, the same pendulum will vibrate more quickly at the pole where the force of gravitation is greater than at the equator where this force is less. It has been calculated that a pendulum one meter long will make 86,242 vibrations per twenty-four hours at the pole and only 86,017 at the equator. In order to make the pendulum vibrate with the same speed at the equator as at the poles, it will be necessary to shorten it slightly at the equator. If this is not done the clock will be slow at the equator. The clock loses time chiefly as a result of the earth's rotation.

A French astronomer, Richer, who went to Cayenne in Guiana in the 17th century made this discovery. He took with him a fine pendulum clock made by a famous firm in Paris. He was annoyed

to find that the clock was going slow. He, therefore, shortened the pendulum slightly and the clock went all right. But when he returned to Paris after some years, he found that the clock was going fast and the pendulum had, therefore, to be lengthened again. It dawned upon him then that it was not the fault of the clock but of the earth's rotation.

### 5. Evidence of the Tides

The tides are caused by the attraction of the sun and the moon which they have on the earth's water. Owing to its nearness to the earth, the moon has greater influence on the tides than the sun. The water of the sea that is facing the moon is drawn towards the moon forming a tide. A similar tide is formed in the sea opposite this point also. The exact cause of this second tide will be noticed in a subsequent chapter. Thus, there are two tidal waves going round the earth. If these tides moved with the moon only, every place on the sea would have a tide every fortnight. For the moon revolves round the earth in about a month, and there are two tidal currents moving at the same time at opposite points. Actually, however, there are tides *twice a day*. This is because the earth is rotating and brings every point opposite to the moon every twenty-four hours. So that the points have not to wait for the moon to come opposite to them by its own revolution round the earth, but are *brought* opposite to it by the earth's rotation.

The earth revolves round the sun on its path or orbit which is elliptical in shape, *i.e.*, differs only a little from a circle. The length of this orbit is about 580,000,000 miles, and the earth covers it in about 365¼ days.[1] This gives a speed of 18½ miles per *second* which is immensely greater than about 18 miles per *minute*, the speed at which it rotates on its axis. In other words, the earth travels round the sun about sixty times faster than it rotates on its own axis.

The earth is being hurled into space at this tremendous speed and yet we are entirely unconscious of it. We never even feel a jerk on this account !

Copernicus, a Greek astronomer (1473-1543) was the first to discover in 1507 that the earth revolved round the sun. His discovery gave rise to *Copernicus system* which regards the sun as the centre of the planetary system, as distinct from *Ptolemic system* founded by Ptolemy who lived in the 2nd century A.D. at Alexandria and who believed that the earth was the centre of the universe[2], *i.e.*, other heavenly bodies moved round the earth and not round the sun.

[1] The actual time taken is 365 days, 5 hours, 48 minutes and 48 seconds.

[2] Copernicus system is also known as 'heliocentric system' and the Ptolemic system as 'geocentric system.'

An obvious proof of the earth's revolution round the sun is the change of seasons of the earth's surface. The earth's movement round the sun, as of all other planets, takes place, anticlockwise. This movement is not at a uniform rate, but it is slightly faster in winter than in summer.

## Rotation sets Time

The two movements of the earth, rotation and revolution, are fundamental in its planetry relations. The earth's rotation has a great significance for Man. It makes the 'day' and the 'night' to regulate normally his period of work and the period of rest. Rotation causes the 'sunrise' and the 'sunset' and thereby provides a basis for reckoning the time. It is many thousands of years ago that man divided the period of rotation into twenty-four hours. He also divided the hours into minutes and minutes into seconds; the usual divisions of a degree of an angle. When the sun reaches the middle point of its apparent path from horizon to horizon, it is said to be mid-day or noon, *i.e.*, twelve o'clock.

It will be realized that owing to the spherical shape of the earth, sunrise, sunset or mid-day will not be the same for all places on the earth's surface. As the earth moves from west to east, the further to the east a place is situated, the sooner it will see the sun and sooner will its mid-day and sunset come. If a person moves to the east one-twenty-fourth part of the earth's circumference, or 15° of longitude, he will see the sun rise an hour earlier. If, on the other hand, he moves to the north or the south, there will be no change in the hours of sunrise or sunset. There are, therefore, lines running north and south that have the same time. These lines are called 'meridians.'* Each meridian will, however, have its own time of sunrise, and therefore, of noon.

It is clear that if each meridian were allowed to keep its local time, modern business would become impracticable, because every neighbouring town or village not on the same meridian would keep a different time. Therefore, by international agreement, the earth has been divided into twenty-four strips or 'time-zones' in each of which the time differs by one hour. Thus everywhere in the world the minutes of the hour are the same, only the hours differ. For instance, it is twenty minutes past eight in England when it is twenty minutes past nine in Germany. It is clear that the 'time-zones' are the broadest at the equator and become narrower the nearer we get to the poles. It means that in the higher latitudes a time-zone is traversed comparatively in a short time, so that travellers have to adjust their watches repeatedly.

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*Medius means middle, and *dies* means day.

All time-zones meet at the poles and, therefore, there is no particular time at the poles. All watches are right there !

As the earth is round, sunrise cannot be said to start from any particular meridian. By international agreement, however, a 'Prime meridian' has been fixed and all other meridians fix their time from the noon at that meridian. Practically all over the world, now the meridian running through the Royal Observatory at Greenwich near London is accepted as the 'Prime meridian.'*

The present system of universal or standard time was given international recognition only after a considerable effort on the part of eminent scientists and scientific associations. It was not until the International Meridian Conference of 1884, held in Washington, that success was achieved. This Conference determined on Greenwich time as the universal world time. Since that time one nation after another has accepted it. The acceptance of the universal time is now a necessity in the constant communication by telephone, telegraph, and radio and transportation by air, rail, motor and water.

A few exceptions are still there. Among these Holland, Newfoundland, Java, Bolivia, Paraguay, Arabia, Persia, Afghanistan are notable.

As has been noted above, the earth is divided into 24 hour-zones. The governing meridians are spaced at intervals of 15 degrees, beginning with the prime-meridian (Greenwich). Each time zone extends 7½ degrees on each side of its governing meridian.

On the oceans, each zone generally conforms exactly to the specified boundaries. There are a few exceptions, however, like the Kurile Islands and Sakhalin which take their time from Japan instead of that of the zone in which they lie.

The 15-degree limit of the time-zone is often deviated from on land to coincide with certain political or regional boundaries. For example, the British Isles, Belgium, France, Spain, Portugal, the Ivory Coast, and the Gold Coast use the same hour as Greenwich, international boundaries do not follow the bounding meridians or this zone. Sweden and Norway, which together cover more than 15 degrees, as also the whole of Central Europe, begin their day one hour ahead of Western Europe. Though British South Africa and Mozambique together lie in three time zones, they all use the time of the middle zone for the sake of convenience. Argentina, instead of using the time of two zones, which cover it, uses only one, that of Buenos Aires. The United States of America has three times, the Eastern time, the Central time and the Pacific time.

* Holland alone is an important exception. It keeps its time by the line passing through the West Church in Amsterdam which differs 19 1/2 minutes from West European time.

## Daylight-saving time

The time-zone system has been recently modified to some extent by the adoption of the Daylight saving scheme. This scheme originated during the first Great War as a measure of economy. After the war it was retained as the urban populations desired for more hours of sunlight after the working day is over. This scheme was operative only in the middle latitudes during the summers, when sunrise is early, sunset late and twilight long. During the last World War the nations are following a scheme of 'Double-Summer-Time' as a measure economy.

## International Date Line

Each new day starts somewhere in the east. But this 'east' may be anywhere, for its position depends on the point from which we determine it. A line, however, must be fixed to the *west* of which the new day is born, while to the *east* of it the old day still prevails. This line is called the International Date Line. It runs through the twelfth time-zone east of Greenwich (which is also the twelfth time-zone west of it) and, therefore, follows the 180th meridian. For practical reasons, it changes its course here or there to the east or the west. In order to avoid confusion, it has been accepted as a convention by the nations of the world that this line be fixed in such a way that it does not run through any country. Most of its course lies on the Pacific. Its exact course is as follows: east of the eastern point of Siberia through the Bering Strait, east of Japan, the Philippines,* New Guinea and New Zealand. In the time-zone through which the International Date line passes, the time followed is the same throughout, but the date differs.

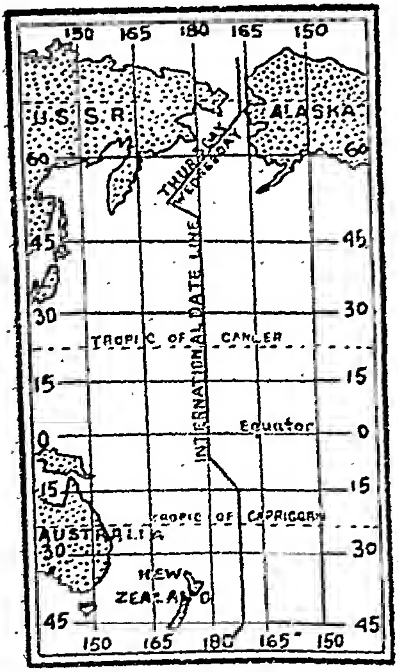


Fig. 7. International Date Line.

*The Philippines belonged to the eastern group until 1845. Similarly, Alaska which belonged to Russia until 1867 was included in the western group. But on its transfer to the U.S.A. it now belongs to the eastern group.

The date line deviates from the 180th degree in three places. It swings through Bering Strait so as to place the eastern corner of Asia in one time-zone. Thence it runs directly south-west to the end of the Aleutian Islands. The third deviation is in the south where the line swings eastward 7½ degrees so as not to complicate time in the Fiji Island and New Zealand. There is no international agreement to define the International Date Line, nor have the nations formally sanctioned it. International custom has, however, located and informally adopted it. In general, except for minor deviations, navigators of all nations use the same line.

The credit for fixing this line goes to Professor Davidson, of the U. S. Coast Survey Office in San Francisco. After his retirement in 1895 he corresponded with all the countries in the Pacific Ocean to find out which kept Asiatic and which the American time. This investigation first located the points where the International Date Line departs from the 180th meridian. The results of this investigation were incorporated in the August Pilot Chart of the North Pacific Ocean published by the U. S. Hydrographic Office in July, 1899. The title reads : "The line separating the lands of the Pacific where American date is kept from those where Asiatic date is kept."

The immediate effect of the International Date Line is felt by the travellers who cross it from one direction or the other. When a ship crosses this line from *west* to *east*, the *date* of the crossing is *repeated*. For example if the ship crosses this line on Thursday, the 3rd of January, the next day for it will also be Thursday, the 3rd January. This will appear in the log book (in which the ship records its observations made on the voyage) as Thursday, 3rd January, I, and Thursday, 3rd January, II. If, however, the crossing is done on a Sunday, the day that will be repeated will not be the Sunday, but Monday. It will be Monday, I, and Monday, II. It has been agreed that Sunday or any other holiday will not be omitted or repeated.

If the ship is travelling from *east to west*, on crossing the line *it loses* a day. Thus, if the ship crosses the line on Thursday, the 3rd January it will lose or drop Friday, the 4th January and Saturday, the 5th January will follow its Thursday, the 3rd January. In the log book, therefore, the next day after Thursday will be Saturday.

This arrangement for repeating or dropping a day is not based on the mere agreement between nations. It is based on a fact resulting from the earth's rotation from west to east. To illustrate this, suppose you have a very swift aeroplane which can take you round the earth in a few seconds, and suppose you start on it from Allahabad in the easterly direction. You will find that in the countries that you fly over, the time will be an hour later each time you cross

a fresh time-zone. When you arrive back at Allahabad, you will have crossed twenty-four time-zones in each of which the time was one hour later. So that, even if you have flown only a few seconds, you have landed back in Allahabad *after twenty-four hours*, after your departure.

Now suppose that you flew to the west, it will be one hour *earlier* in every time-zone that you cross. After crossing twenty-four time-zones, therefore, you will return to Allahabad twenty-four hours *before your departure*. This is absurd. There must, therefore, be a date line on crossing which, a change in the date should be made.

One can always make a given day last longer by travelling westwards, for he has the benefit of an *earlier appearance* of the sun at the place from which he starts in the morning and of its *later disappearance* at the place where he arrives in the evening.

If a person begins flying around the earth in the westward direction at the same rate as the apparent movement of the sun from a given point at noon, with his watch set at that hour. When he has flown over 15° of longitude, it will be noon by the sun, but 1 P.M. by his watch. When he has flown over 90° of longitude it will still be noon by the sun, although his watch records 6 P.M. As he continues his journey around the earth, it will continue to be noon for him, by the sun, of the same day on which he started, though his watch will have run twenty-four hours. Thus be seems to have gained an entire day. In reality, however, he has been lengthening his day at the rate of one hour for every 15° of longitude crossed westward. If he had adjusted his watch to the time of the time-zone in which he arrived he would have turned his watch by one hour twenty-four times in his flight around the earth. He is, therefore, one day behind in his counting of time. He must, therefore, move forward his reckoning by one day.

An east bound traveller, on the other hand, is constantly shortening his days He is always starting from a place where the sun appears later, and arriving at a place where the sun disappears earlier.

Suppose a person begins a round-the-earth flight eastwards, at noon, and suppose he flies at the same rate as the sun's apparent movement west westward. He travels 15° of longitude eastwards every hour, while the noon moves over 15° of longitude westwards in the opposite direction every hour. The distance between him and the place where there is noon increases, therefore, by 30° of longitude every hour. That is to say, noon is travelling westward at the same rate as he is travelling eastward. So that when he has gone half way around the earth, he will again have noon. When he reaches his destination he will find that noon has also reached it from the other direction. Although only twenty-four hours have passed

since he started on the journey, he seems to have spent two days over it as he has twice seen the sunrise, noon, sunset and midnight. He is, therefore, a day ahead of the correct time and so must repeat a day.

Whenever a person travels around the earth, there is a difference of a day between his time reckoning and that of the place where his journey ends, regardless of the speed and the time taken by the journey. This difference is adjusted by changing dates at the date line.

A new day is born at the western boundary of the International Date Line and pushes from east to west in stages of an hour. Every hour it occupies a new time-zone ; until at the end of twenty-three hours it has reached the eastern boundary of the time-zone in which the date-line is situated. As soon as it reaches the date-line, it must end its career and give place to its successor which had already been born and had been pushing the first day from behind. Thus, owing to the date line, every day lasts for forty-eight hours !

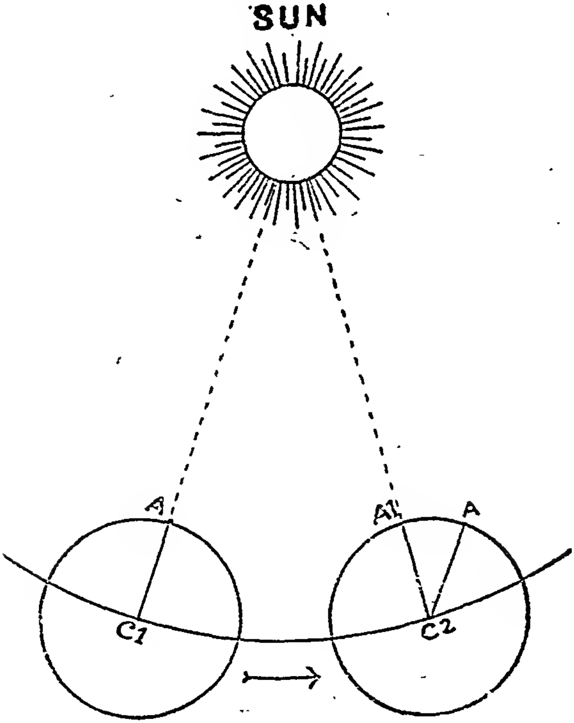


Fig. 8.

Of necessity, our regulation of time is artificial. Our clocks show a time that is based neither on rotation of the earth nor on the local noon. It is based only on practical convenience. In the first place, the time of a given meridian must be made universal for a whole time-zone or a country, and thus the true meridian time is departed from. In the second place, mean time instead of the true solar time has to be adopted. For, due to the different speeds of the earth, *true noon* comes after the *mean noon* as indicated by the clocks with increasing difference. In other words, the sun passes the meridian later every day.

This point can be illustrated from the diagram No. 8 given above.

$C_1$ and $C_2$ are the two positions of the earth on two consecutive days. In position $C_1$, the Point A is having its noon. As is known, while the earth rotates on its axis it also moves forward on its path round the sun. On the second day, therefore, the earth will reach position $C_2$ where it will have to rotate a little further from A to $A_1$ to bring the point A to its noon-day position. This will take it 3 minutes 56 seconds. That is to say, the true noon at the point A on the second day will be about 4 minutes tater than the civil noon which is 12 o'clock by the clock everyday.

The earth, however, does not travel round the sun at a uniform rate. It goes slightly faster in winter than in summer. In winter, therefore, it will reach a position further to the right and the four

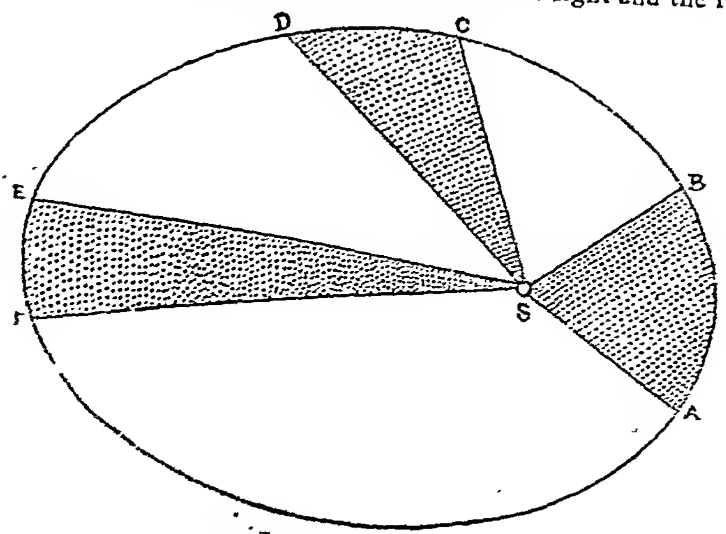


Fig. 9. Showing Earth's Speed on its Orbit.

minutes will be insufficient to bring the point A to the noon-day sun. Thus, the true noon differs from the civil noon, day by day, not only because the earth revolves round the sun at the same time as it rotates, but also because the speed of revolution is not uniform.

The following diagram illustrates the fact that the earth travels faster when it is nearer the sun than when it is farther.

This is according to Kepler's second law which says that, "the motion of each planet in its orbit is such that equal sectors are described in equal times."

The earth travels the distance AB when it is close to the sun (that is to say, when the earth is in Perihelion). When it is farther away from the sun, the distance CD is travelled in the same time; while the distance EF is travelled when the earth is farthest from the sun (that is to say, when it is in Aphelion).

The earth's rotation takes exactly 23 hours 56 minutes and 4 seconds. This can be verified by noting the position of any particular star on successive nights. If we take accurate note of the moment at which that star, in its apparent daily journey round the earth passes an imaginary line in the sky, we shall find that this is repeated the following night exactly 23 hours 56 minutes 4 seconds later. As we know that the apparent motion of this star, as of all other heavenly bodies, is in reality caused by the earth's rotation, the time taken by this rotation is, therefore, 23 hours 56 minutes 4 seconds The time taken by the earth's rotation is called the '*Sidereal day*'[1]. The time that separates one noon from the following noon on the same meridian as shown on the sundial is called the '*Solar day*.' The computed day of a constant length of 24 equal hours as shown by clocks is called the '*Mean Solar day*'. The difference between the mean solar day as shown by the clock and the solar day as shown by sundial is called the '*Equation of time*.' It may be expressed thus :—

Mean Solar Time=Apparent Solar Time—Equabonot time. This difference may be as much as 16 minutes.

The following table[2] gives the time of the true noon over Greenwich meridian for certain dates :—

| Date | Time H. M. | Equation of time. Min. | Date | Time H. M. | Equation of time. Min. |
|---|---|---|---|---|---|
| Jan. 1 | 12·04 | — 4 | April 1 | 12·04 | — 4 |
| ,, 15 | 12·10 | —10 | ,, 15 | 12·00 | 0 |
| Feb. 1 | 12·14 | —14 | May 1 | 11·57 | + 3 |
| ,, 11 | 12·14½ | —14½ | ,, 15 | 11·55 | + 5 |
| Mar. 1 | 12·12 | —12 | June 1 | 11·57 | + 3 |
| ,, 15 | 12·09 | — 9 | ,, 15 | 12·00 | 0 |

1 Siders is a Lation word meaning Star.

2 Taken from the American Ephemeris and Nautical Almanac, 1942, pp., 2-16.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| July | 1 | 12·03 | — 3 | Oct | 15 | 11.46 | +14 |
| ,, | 15 | 12·05 | — 5 | Nov. | 3 | 11·43 | +17 |
| ,, | 26 | 12·06 | — 6 | Nov. | 16 | 11·44 | +16 |
| Aug. | 15 | 12·04 | — 4 | Dec. | 1 | 11·49 | +11 |
| ,, | 31 | 12·00 | 0 | ,, | 15 | 11·55 | + 5 |
| Sept. | 15 | 11·55 | + 5 | ,, | 25 | 12·00 | 0 |
| Oct. | 1 | 11·49 | +11 | | | | |

It is seen from the table above the solar day and the mean solar day coincide on four days in the year. These days are :—April 15, June 15, August 31, and December 25. The greatest difference 17 minutes between the solar day and the mean day is on November 3.

The following is the graphical representation of the above table :—

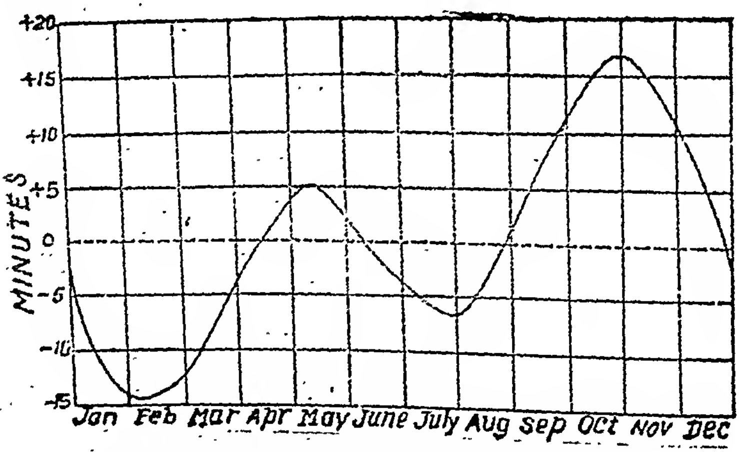


Fig. 10. Graph showing Equation of Time.

(Dotted line shows the clock or Mean Time, while the curve shows the Sundial or Solar Time).

Related to the different speeds at which the earth revolves round the sun (see Fig. 9) is the fact that in the northern hemisphere although the days begin to lengthen after December 22, the sun rises later for several days. This is because the earth is rapidly slowing down in speed and the time of sunrise as well as of sunset is, therefore, delayed.

The two most important facts resulting from the planetary relations of the earth, the earth being a planet, are : (1) it rotates on its axis ; and (2) it revolves round the sun.

Rotation has given the earth its shape. It gives it an alternation of day and night and has determined its time. It also affects the direction of the moving things on the earth's surface, *e.g.*, the deflection in the direction of winds and of ocean currents.

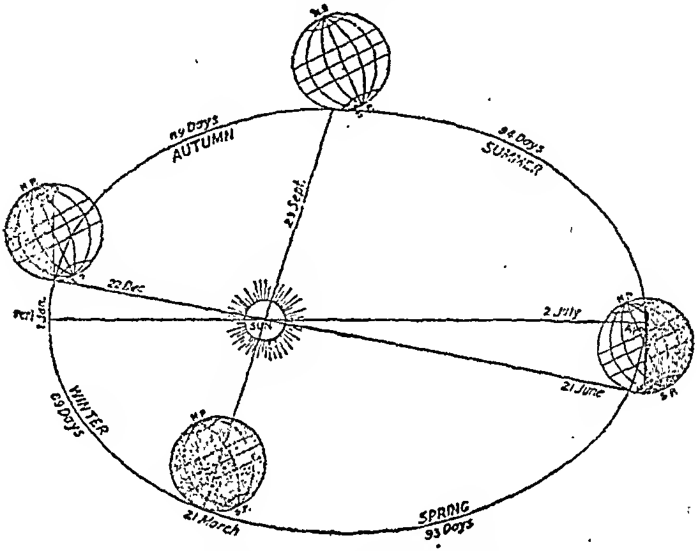


Fig. 11. Earth Revolution Round the Sun.

Revolution, on the other hand, affects the distribution of solar energy on the earth's surface and determines its seasons. It also makes man's calendar which keeps a count of time.

The most outstanding fact that emerges from the study of the diagram above is that the earth's axis keeps pointing in the same direction into space in all its position, in the orbit round the sun. This is the only cause of the occurrence of the seasons on our earth.

The astronomers tell us, however, that this direction is only temporarily fixed. The direction of the earth's axis goes on changing in a small celestial circle among the stars. The earth's axis describes this circle in 25,800 years. This means that our present Pole Star will cease to be the Pole Star after about a thousand years. It will be the Pole Star again after 25,800 years from that date. The moving of the direction of the earth's axis in a small circle is called the 'Precession of the Equinoxes.'

At the present moment the position of the pole is approaching Alpha Ursae Minoris and is now very nearly one degree from it. The approach will continue until the year 2102, when the distance

will reach its minimum value of 28 minutes of arc, an angle somewhat less than that subtended by the disks of the Sun and Moon.

In about 12,000 years' time the brilliant Vega will be the nearest bright star to the pole, but it will not be so close to it as is our present Pole Star. In fact in the whole length of the precessional cycle no other conspicuous star can ever mark this important position with such an approach to exactness.

The south celestial pole, in contrast to the northern, is not marked by any conspicuous object, nor will the pole be anywhere near to a really bright star for many thousands of years to come.

At 10 a.m. on March 21 the Sun crosses the celestial equator in a south-to-north direction, and the time of its crossing marks the Spring Equinox of the Northern and the Autumnal Equinox of the Southern hemisphere. The term equinox is often erroneously taken to mean that at this date the day is equal in length to the night, whereas it is really intended to indicate that the nights and days are respectively equal at all latitudes.

That they are by no means equal to one another will be seen by reference to the times of sunrise and sunset given in the almanac. Thus on March 21 in the latitude of London, the Sun shines theoretically for 12hr. 10min., while the length of the preceding night is only 11hr. 50min.; and it is the fact that these respective durations are the same for all latitudes which justifies the term applied to the phenomenon.

That the two are not equal to one another is due to two distinct causes. In the first place it is an ideal point—the Sun's centre—which is crossing the Equator at the moment of the Equinox, whereas the times of sunset and sunrise are calculated for the instants at which the upper edge of the Sun's large disk is on the horizon, and this naturally gives a later sunset and an earlier sunrise than would be calculated for the Sun's centre.

Secondly, a still greater discrepancy is caused by the apparent raising of the Sun by atmospheric refraction. This raising effect is in fact so great that, near the horizon, it exceeds the angular diameter of the Sun, so that when the latter is wholly below the horizon, its entire disk is still in full view. Hence there is a considerable delay in the final disappearance of the Sun at sunset and an acceleration of its appearance at sunrise.

If the Sun were a mere point and the Earth had no atmosphere the days and nights would indeed be of the same length at the equinoxes for an observer at sea level; and throughout the year the sunny and sunless hours would add up to the same figures, whereas for the reasons given above the former must exceed the latter at all places on the Earth's surface.

CHAPTER III

# THE ATMOSPHERE

NATURE AND EXTENT OF ATMOSPHERE—COMPOSITION—STRATOSPHERE—TROPOSPHERE—INSOLATION—CIRCLE OF ILLUMINATION—FINDING LATITUDE BY NOON-DAY SUN—TWILIGHT.

The earth is surrounded by a cover of gases called the Atmosphere. It surrounds the earth to a height of several hundred miles. Man and other forms of life, therefore, live at the bottom of this sea of gases from which they can never escape. Any changes that take place in the condition of the atmosphere, therefore, fundamentally affect us. It is from this point of view that the study of the atmosphere is of great significance. The science that studies the atmosphere is called Meteorology. Meteorology, however, limits itself to the study of the lower atmosphere only; the upper atmosphere is studied by Aerology which was recognised only about the close of the last century.

The study of meteorology is based upon direct observations of the atmospheric conditions and the deductions drawn from these observations. Considering the great depth of the atmosphere around us, our means of access into it are inadequate. The observations are, therefore, meagre, and the deductions based upon such observations are not quite satisfactory. The study of meteorology is, to some extent, therefore, speculative.

The means by which we can ascend into the atmosphere and which provide the sources of meteorological information are the following:—

1. Mountain heights.
2. Aeroplanes.
3. Kites.
4. Manned balloons.
5. Sounding balloons.

Except the last, these means do not take us beyond the region of clouds and ordinary dust. Assuming that the atmosphere extends upward to a height of about 300 miles, these means give us access only to a small fraction of it.

For getting knowledge of the higher elevations, the appearance of certain phenomena is observed and deductions are made from it. These phenomena are:—

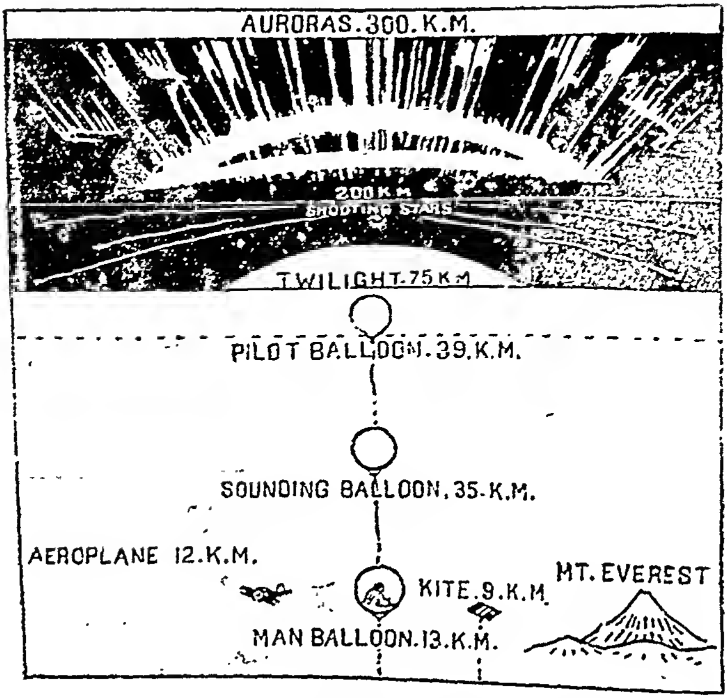


Fig. 12. Wegener's Profile of Air Mass

(*a*) Twilight arch, (*b*) Shooting stars, (*c*) Auroras, and (*d*) Lightening flashes.

The diagram above shows the various sources of meteorological information, with approximate elevations up to which they are effective.

## Composition of the atmosphere

The atmosphere is composed of a number of gases. The outstanding feature of this composition is that more than 99 per cent of the atmosphere is made up of two gases nitrogen and oxygen. All other components make up less than 1 p. c. of it.

Another feature of the composition is that the denser gases predominate in the lower reaches, while the lighter gases make up the major portion of the upper reaches of the atmosphere.

Water vapour and dust may also be considered as constituents of the lower atmosphere. The proportion of water vapour in the atmosphere varies with temperature. More water vapour is present in the warmer than in the cooler air. Because of this relation of

water vapour to temperature, its proportion in the air decreases in the lower atmosphere from the Equator towards the Poles, while the proportion of other constituents increases. The following table shows the annual average values of the various constituents of the atmosphere at certain latitudes :—

| Latitude | Components % | | | | |
|---|---|---|---|---|---|
| | Nitrogen | Oxygen | Argon | Water vapour | Carbon dioxide |
| Equator | 75·90 | 20·44 | 0·92 | 2·63 | 0·02 |
| 50°N. | 77·32 | 20·80 | 0·94 | 0·92 | 0·02 |
| 70 N. | 77·87 | 20·94 | 0·94 | 0·22 | 0·03 |

Except for the change in the amount of water vapour, the composition of the surface atmosphere is substantially the same at all parts of the earth.

The following table shows the distribution and pressure of the atmosphere at certain heights :

| Height km. | Nitrogen | Oxygen | Argon | Water vapour | Ca bon dioxide | Hydrogen | Total Pressure in MM |
|---|---|---|---|---|---|---|---|
| 100 | Decrease starts from 60 km. 8·12% | | | ... | | Increases 100 km. 95·5% | |
| 90 | | | | 0·10 | | | |
| 80 | | | | 0·17 | | | |
| 70 | | | | 0·20 | | | |
| 60 | | | | 0·15 | | | |
| 50 | | | | 0·10 | | | |
| 40 | | | | ... | Nil | | |
| 30 | 84·26 | 15·18 | 0·35 | 0·03 | 0·01 | 0·16 | 8·68 |
| 20 | 81·24 | 18·10 | 0 59 | 0·02 | 0·01 | 0·04 | 40·99 |
| 11 | 78·02 | 20·99 | 0·94 | 0·01 | 0·03 | 0·01 | 168 |
| 5 | 77·89 | 20·95 | 0·94 | 0·18 | 0·03 | 0·01 | 405 |
| 0 | 77·14 | 20·69 | 0·93 | 1·20 | 0·03 | 0·01 | 760 |

[From Humphreys]

Note from the above table the following points :—

1. Most of the water-vapour is contained in the lower limits of the atmosphere, up to 5 km. Its proportion, however, begins to increase from 11 km. to 80 Km.
2. The air pressure decreases precipitately from 11 km. upwards.
3. Hydrogen which is a representative of lighter gases increases upwards, until at 100 km. it constitutes 95·5 % of the atmosphere.

The atmosphere is studied in two parts. The lower part is called the *Troposphere* or the convective region, and the upper part, *Stratosphere* or the isothermal region. In the troposphere temperature decreases with the increase in altitude. But beyond a certain elevation, about 8 miles, temperatures remain constant. This region of constant temperatures is the stratosphere. The boundary between the two region is called *Tropopause.*

## Stratosphere

The discovery of the fact that the temperature of the upper atmosphere changes but little with altitude constitutes one of the most important advances in meteorology. The credit for this discovery goes to Teisserenc de Bort, who, in April 1898, began at Trappes, in France, a long series of frequent atmospheric soundings with improved apparatus.

The height at which this region begins, and its temperature, both depend upon season, upon storm conditions, and upon latitude.

Gold of England and Humphreys of America soon produced an explanation for its existence. The explanation is this : the temperature of every portion of the atmosphere is determined, in part at least, by counteracting radiation—radiation absorbed and radiation emitted—and wherever these two are equal there is a substantial constancy of temperature.

The stratosphere is at a greater height during summer than during winter.

The lowest temperatures so far observed in the stratosphere are :—

| Temp. | Height (Meters) | Remarks |
|---|---|---|
| —80°C | at 14,800 meters | in U. S. A. |
| —82°C | at 14,500 ,, | over the Atlantic (8°S latitude) |
| —84°C | at 19,800 ,, | in Eastern Africa |
| —85°C | at 9,700 ,, | at Vienna |
| —90·9°C | at 16,500 ,, | in Java |

The temperature in the stratosphere is lower at the Equator than in other regions. The temperatures of—80°C are common there. In the temperate zone the temperature varies from—50°C to—60°C. At great heights, say for example, at 10 miles, it is colder at the Equator than at other latitudes.

The reason of this is that the warm surface temperatures in the equatorial regions cause, through vertical convection, abundant cloudiness at high altitudes. These clouds intercept much of the radiation from below.

In the northern hemisphere, during summer, the under surface of the stratosphere gradually rises from about 6 miles above sea level at latitude 60° to approximately 9 miles at the equator. Note these features in the following diagram :—

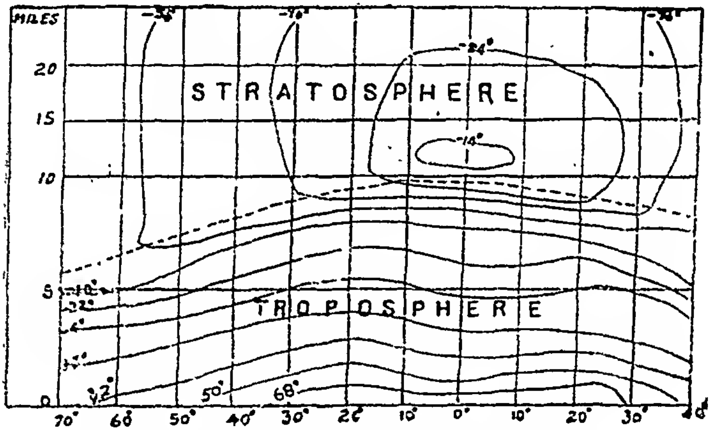


Fig. 13. Temperature Sun in Stratosphere.

The sun is the great source of heat at the earth's surface. The sun whose diameter is more than one hundred times the diameter of the earth, and whose temperature is estimated to be more than 10,300°F. or 6,000° Absolute is a radiant mass of gas. It, therefore, gives out tremendous amounts of energy all round. The earth catches only about $\frac{1}{2,000,000,000}$ part of this energy. Even though insignificant when compared with the total sent out by the sun, this energy is the basis of all life and all activity on the face of the earth. Between the earth's surface and the sun, however, lies the atmosphere. The solar energy must, therefore, pass through the atmosphere.

The atmosphere occurs in layers. Its upper layers have reflecting surfaces. Part of the solar energy, therefore, is reflected back into space by these reflecting layers of the atmosphere. The clouds present in the atmosphere also reflect solar energy.

Besides, the atmosphere consists of various gases. Some of these gases absorb part of the solar energy. Dust particles and water vapour also absorb some of the energy. The result is that, because of intervention of the earth's atmosphere, even this 1/2 billionth part of the solar energy caught by the earth is diminished considerably.

Kimbal* has estimated the following distribution :

Total 200% of which
42% reflected back into space.
11% absorbed by water vapour in the atmosphere.
4% absorbed by gases and dust.

57% Lost.
43% Reaches the earth's surface and absorbed by it.

Thus, about *one-half of the solar energy coming to the earth is lost in transmission through the air.*

Insolation means the incoming of the solar radiation on the earth. [In-sol (ar) (radi)-ation.] Based on the observations of Abbot and others during the period of 1905-1926, the solar radiation is estimated to be 1·94 calories per sq. centimetre per minute. This amount seems to be, more or less, constant. It is, therefore, called '*solar constant*'.

The 'solar constant', however, is not fixed. For the solar energy radiation differs from time to time. When considered minutely, the solar radiation depends on the number of sunspots. It varies between the spot maxima and spot minima. When the sunspots are the greatest in number the solar radiation is more than when they are fewer.[1]

The distance of the earth from the sun also varies. It is roughly, 3·3 p. c. greater at aphelion[2] than at perihelion. Hence insolation at perihelion, other things being equal, must be approximately 6·6 p. c. greater than at aphelion. This is equal to about 4°C.

Notwithstanding the marked difference between the perihelion and aphelion intensities of the solar radiation at the limit of the atmosphere, the total amount of insolation on the earth as a whole is constant ; and that the hemisphere, regardless of the perihelion

*Monthly Weather Review, 1928.

[1]The average temperature of the earth as a whole though much pronounced in the equatorial regions, is a little higher at the times of spot minima when the solar constant is the least than at the times of the spot maxima when it is the greatest. Abbot thinks that this may be due to a decrease in the amount of ozone in the upper air owing to the increased solar energy. Ozone acts as a blanketing agent, owing to its powerful absorption of the radiation from the earth. Hence a somewhat lower temperature would result on the earth's surface. The position is similar on a clear as contrasted to a clouded night.

2 Aphelion=94·5 m. miles. Perihelion=91·5 m. miles apo=away, peri= near helion=sun.

phase, or exact date on which perihelion occurs, receives during the course of a whole year exactly the same amount of solar radiation as the other.

Even though the insolation received on the earth's surface as a whole is constant, it differs from place to place and from time to time due to the following factors :—

(*a*) Altitude of the sun and
(*b*) Atmosphere to be crossed.

Because the earth is approximately a sphere, only about half of it receives the sun's rays at one time. The other half is away from the sun and has its night. Because of the round shape of the earth, there will always be one point at which the sun's rays will be received vertically. The greater the distance a place is from that point, the more slanting are the rays that it receives.

The sun's rays received on the earth are all *parallel* to each other. Slanting rays owe their name to the curvature or 'slant' of the earth's surface. In the following diagram the rays A, B and C are all parallel, but owing to the curvature of the earth they are received at different angles by men standing at different latitudes at noon there. At the equator they form an angle of 90°, *i.e.*, they are vertical. At 30° latitude, they form an angle of 30° with the zenith and are less slanting than at 60° latitude where they form an angle of 60° with the zenith.

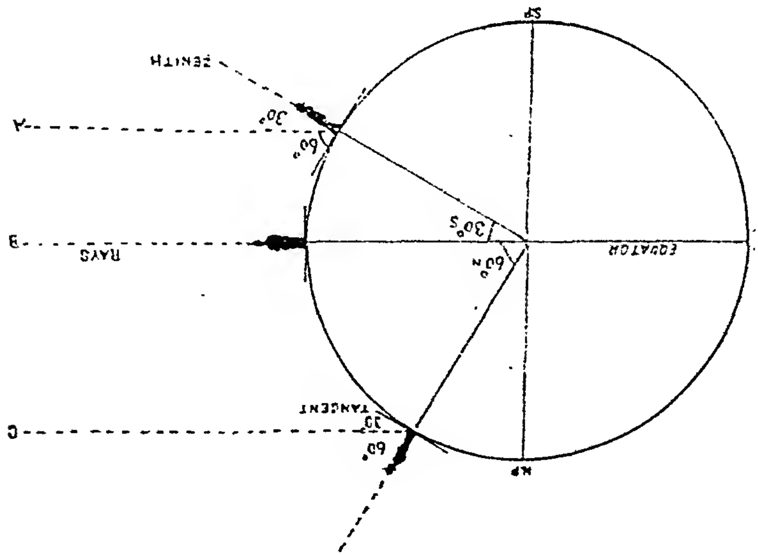


Fig. 11.

The heating intensity of the Sun's rays is directly proportional to the sine of the angle that measures how high the sun is above the horizon. In other words, the more slanting the rays, the less the heat they can give. The heating intensity of the rays wanes as the sine of the angle which measures the altitude of the sun.

Thus, if we let 1 represent the heating intensity of a ray received on the earth at an angle of 90° (at Equator), then the intensity of a ray received at an angle of 66½° (Tropics line) will be ·917: and at an angle of 60° it will be ·866, at 270 it will be ·500 only.

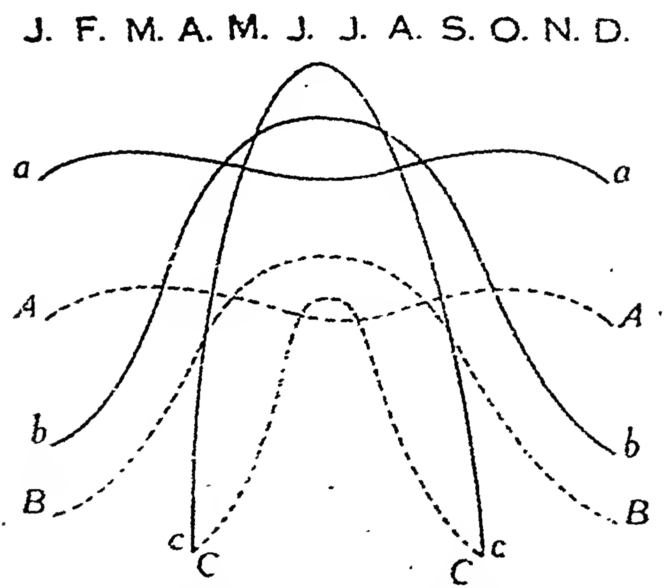


Fig. 15. Showing sun's heat received in certain parts of the Earth. Thick lines show amount unmodified by atmosphere. Dotted lines showing amount reduced by atmosphere. Letters on top are for months of the year. Lines a A are for the Equator to B for 45°N., c C for North Pole.

[After Angot]

There is very little difference in the heating intensity of the rays received at angles of 90° and 60° but when the angle begins to be very oblique, there is a rapid decrease in heating intensity.

The table given below shows that the path of the rays of the sun through the atmosphere lengthens disproportionately as the height of the sun above the horizon decreases :

| Sun's Altitude | Length of Path through Atmosphere |
|---|---|
| 90 (At Equator) | 1 |
| $60^0$ | 1·15 |
| $30^0$ | 2 |
| $10^0$ | 5·7 |
| $0^0$(At Poles) | 44·7 |

[After Peterssen]

Less slanting the sun's rays received, the less heat energy they have lost in passing through the atmosphere, and smaller the surface area of the earth over which they are spread. This explains why the regions near the equator are warmer than those in high latitudes. That is also the reason why it tends to be warmer at noon than in early morning and late afternoon when the rays are slanting. Fig. shows the effect of atmosphere on the distribution of solar insolation.

The following diagram shows that the path *ba*, near the Poles, is longer than the path *b'a'*, at the Equator :

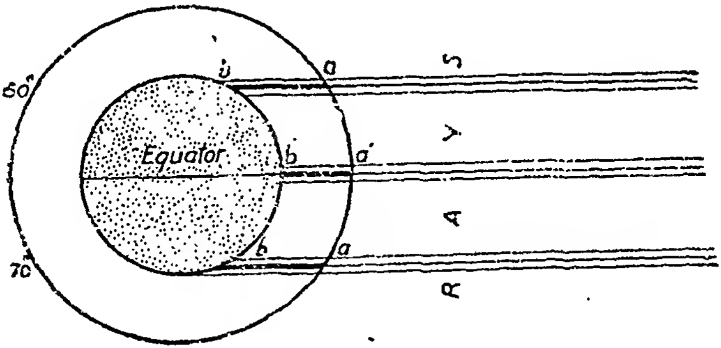


Fig. 16. Path of sun's Rays through Atmosphere.

The earth's revolution round the sun and the inclination of its axis to the plane of its orbit lead to the shifting of the direct rays of the sun on the earth's surface from time to time. This shifting also, therefore, effects the distribution of insolation on the earth's surface. Owing to this shifting, the higher latitudes receive greater insolation during the summer than during the winter. Insolation is directly related to the duration of sunlight. Longer the hours of sunlight, greater is the amount of insolation received. The hours of sunlight depend upon the angle at which the circle of illumination cuts the parallels of latitude. That is why the North Pole has a six months' day during summer. This long and continuous daylight accounts for the large amount of insolation expected

at the Pole (shown by the continuous line C in Fig. 15) and actually received in spite of the long path through the atmosphere. Fig. 15 shows that during June and July the North Pole receives more insolation than the Equator itself.

The great circle that divides the lighted half from the dark half of the earth is called the *circle of illumination*. Rotation and revolution of the earth cause this circle to be ever shifting in position.

Rotating on its axis the earth revolves round the sun. The axis rotation is, however, not perpendicular to the plane of the earth's orbit. It is inclined away from the perpendicular by about 23½ degrees (23°27 to be exact). The position of the axis when the earth is in one part of its orbit is parallel to its position by any other pass of the orbit. The result is that only twice during the earth's course on its orbit does the circle of illumination pass through the poles. At all other times it crosses the parallels of latitude obliquely. The inclination of the earth's axis causes the circle of illumination at one time to extend beyond one or the other of the poles, alternately, and to be short of it at another time. Since the angle of inclination is about 23½°, the circle of illumination will extend around the earth, on June 21, from a point 23½°, beyond the north pole to a point that is 23½° away from the south pole. On December 22, the position will be reversed. The circle will then extend 23½° beyond the south pole and be short of the north pole by this amount. This is illustrated in the following diagram :—

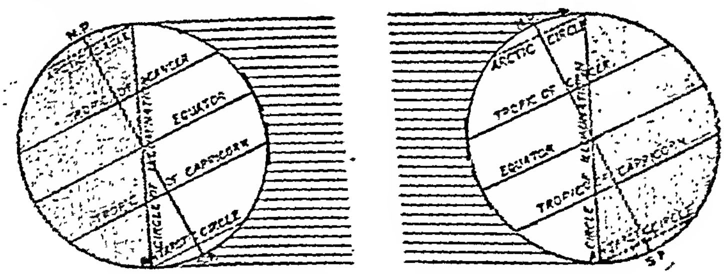


Fig. 17. Effect of Axis inclination on Day-light Hours.

On other days the extent of this extension will depend upon the latitude on which the sun's rays are vertical. If the sun is overhead at noon north of the equator, that latitude equals the number of degrees the circle of illumination lies beyond the north pole. If the sun is overhead at noon south of the equator, that latitude equals the number of degrees the circle of illumination is short of the north pole and extends beyond the south pole. Thus on April 1, the sun is overhead at noon at about 5°N. The circle

of illumination will then extend 5° beyond the north pole and will be short of south pole by 5°. The exact latitude at which the sun is overhead at noon on any day is given in the World Almanac under the heading 'Apparent Declination of the Sun'. The world 'declination' corresponds to latitude.

The angle which measures the distance the sun is away from the zenith of the observer at noon, corresponds to the distance he is in degrees from the latitude at which the sun is shining overhead at noon, and hence is equal to it. In Fig. 18. the zenith distance of the sun at noon has been computed. When the zenith distance of the sun is mentioned, the point from which the measurement is made is the zenith of the observer, *i.e.*, the sun appears so many degrees from the *zenith*. When, however, the measurement is made from the *horizon*, we get the *altitude* of the sun. The instrument used in measuring the altitude or the zenith distance is generally the 'Sextant'.

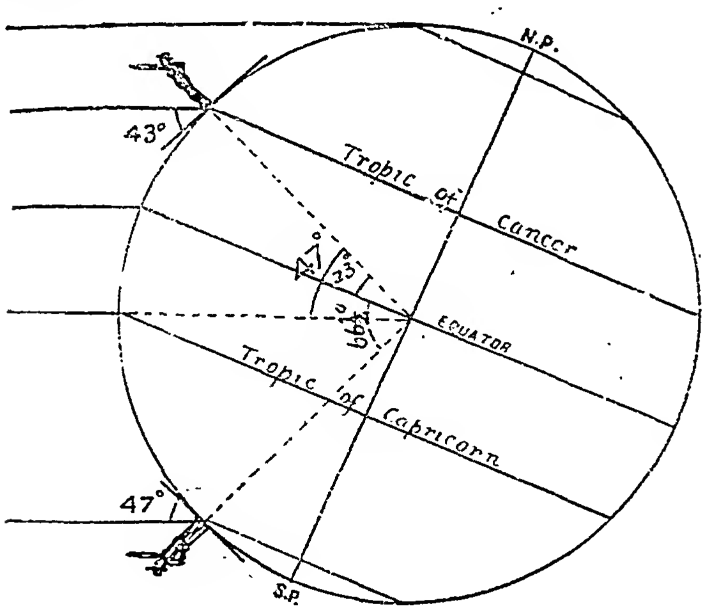


Fig. 18.

The daylight hours depend upon the angle at which the circle of illumination cuts the parallels of latitude On March 21 and September 23, the circle of illumination passes through the poles and bisects every parallel of latitude. On these days the sun is above the horizon for about 12 hours and below it for less than 12 hours. As

the equator and the circle of illumination are great circles, and as the great circles on a sphere divide themselves into equal parts at whatever angle they cross, the circle of illumination always bisects the equator. The days and nights are, therefore, always equal at the equator. The sun always rises at about 6 and sets at about 6. A great circle divides other circles (*i.e.*, latitudes) into equal parts only when it crosses them at right angles. The circle of illumination crosses the parallels of latitudes at right angles only on March 21 and September 23. That is why the day and the night are equal at all latitudes on these dates. At other longer days occur in the hemisphere in which the sun is shining overhead and longer nights in which the sun is not overhead.

In the hemisphere in which the sun is shining overhead the daylight hours increase from 24 at about latitude $66\frac{1}{2}^{\circ}$ to 6 months at the poles.

The possible number of hours of sunshine on the solstices and equinoxes are given in the following table :—

Day Light Hours

| Latitude | Solstice June 21 | | Solstice December 22 | | Equinoxes March 21 September 23 | |
|---|---|---|---|---|---|---|
| | H. | M. | H. | M. | H. | M. |
| 0° (Equator) | 12 | 8 | 12 | 9 | 12 | 8 |
| 10° | 12 | 42 | 11 | 32 | 12 | 8 |
| 20° | 13 | 20 | 10 | 55 | 12 | 9 |
| 30° | 14 | 5 | 10 | 14 | 12 | 10 |
| 40° | 15 | 1 | 9 | 20 | 12 | 10 |
| 50° | 16 | 22 | 8 | 4 | 12 | 10 |
| 60° | 18 | 52 | 5 | 52 | 12 | 13 |
| 70° | 24 | 0 | | 0 | 12 | 23 |

The following is a diagrammatic representation of the above table :—

[To find the latitude by the noon-day sun :—

1. Observe the altitude of the noon-day sun above the horizon by means of a sextant ;

2. Find out the zenith distance of the sun by deducting this altitude from 90° ;

3. *Add* the degree of the latitude where the sun shines overhead on that day (given in the Almanac) to the zenith distance, if in the same hemisphere ; *Deduct* it, if the sun shines overhead in the other hemisphere.

Thus in Fig. 18 for December 22 the sun is shining overhead at the Tropic of Capricorn.

The altitude of the noon-day sun, observed by a sextant at a certain latitude in the northern hemisphere comes to 43°. The zenith distance, therefore, is 90°—43° —47°. As the sun is overhead in the other hemisphere, we find the required latitude by deducting 23 1/2°, the latitude of the tropic of capricorn where the sun is shining overhead from 47° .We get 47°— —23 1/2—23 1/2.

The required latitude is, therefore, the Tropic of Cancer.

Note from the above diagram the fact that the amount of change within a given time increases rapidly in the higher latitudes. For example, during the month of June the change from 20° to 30° makes the day longer by 45 minutes only in the northern hemisphere. But the change from 50° to 60° adds 5 hours.

### Twilight

Like the sunlight twilight is also a phenomenon that depends upon the rotation and revolution of the earth. Before the sun appears on the horizon and after it has disappeared below it, there is sufficient light for most of the outdoor activity. This light is called

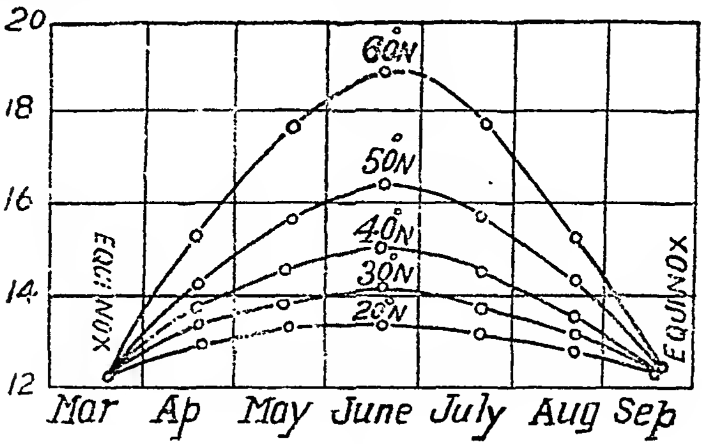


Fig. 19.

the twilight. The twilight is nothing but the sunlight which has been *reflected* and scattered by the atmosphere while the *sun is below the horizon*. This reflection is similar to the reflection of the sun's rays with the help of a mirror. In the case of the mirror, the rays are taken on it and concentrated there and then reflected in a concentrated form. So that they brighten the corner of the room to which the reflection is directed. In the case of the atmosphere, the reflection is *scattered* and not concentrated.

Over a belt about 1,250 miles in width measured from the place, where sunset or sunrise is taking place, there is such a twilight. There are three classes of twilight as follows :—

"Civil" twilight is defined as ending when the Sun has set long enough to be six degrees below the horizon. By this time most outdoor activities cease to be practicable, though the sky is still bright enough to preclude the visibility of all but the brightest stars.

"Nautical" twilight is said to end when the depression of the Sun amounts to 12 degrees. The sea horizon is then no longer visible, so that direct measures of the altitudes of stars can no longer be made by navigating officers. All but the fainter stars are now to be seen and the general effect, especially in illuminated streets, is practically that of true night. But in country districts, away from artificial lights, the sky background still appears pale, and it has been reckoned that all effects of sunlight have not disappeared until the Sun is 18 degrees below the horizon. This marks the end of "astronomical" twilight, after which there is no increase in the darkness of the sky.

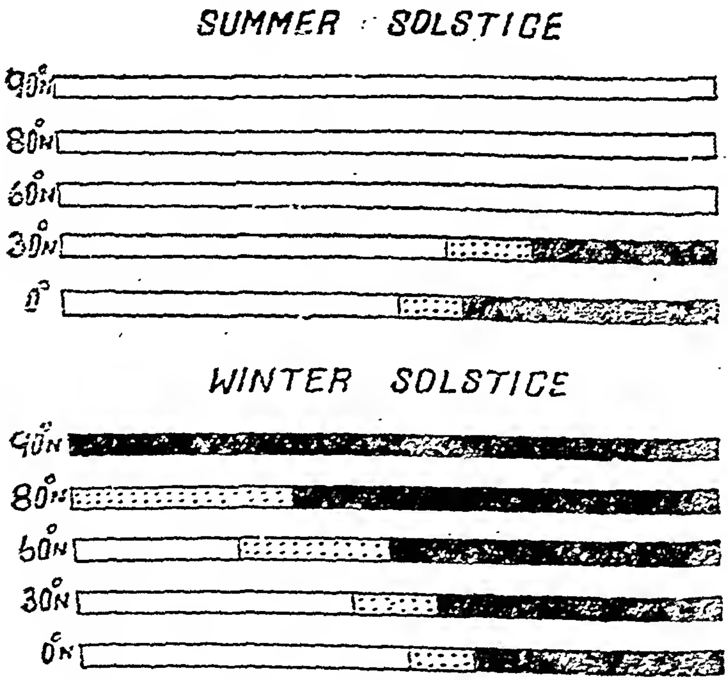


Fig. 20. Twilight and darkness. Dotted portion shows Twilight and the solid black, darkness.

The duration of each of the three subdivisions of twilight depends upon the latitude of the observer. On and near the equator the Sun descends nearly vertically and therefore takes a shorter time to reach any particular depression than in places far north or south, where it crosses the horizon at a low angle. Even at the equator civil twilight lasts as long as 21 minutes, and it is more than an hour before all traces of daylight have left the sky.

In the higher latitudes, especially during the summer months, there is a great difference between the duration of civil and astronomical twilight. During June and the greater part of July the sun is never so far below the horizon at latitudes above 50°N. as to cause complete darkness.

The diagrams below show that the duration of twilight rapidly increases with an increase in latitude. On March 21 and September 23, twilight lasts throughout the night at latitude 80° north or south. At the equator, however, it lasts for only one hour. Near the poles, the twilight may be almost as bright as daylight during the middle of those days on which the sun does not rise there. It is estimated that the sun cannot be seen from about March 24 until about September 20 at the south pole, but that there is twilight for several weeks before it becomes dark enough for the stars to be bright, and that a similar period of twilight probably occurs before the sun appears at the close of winter. At the north pole, a very dim twilight begins about the first of February and brightens gradually until the sun comes above the horizon in March. At 80° N.,

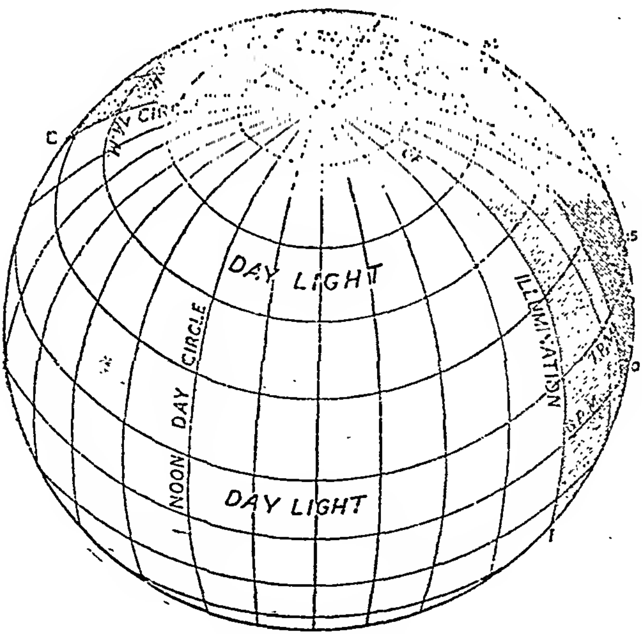


Fig. 21. Duration of Twilight on March 21.

although the sun rises and sets each day from about the middle of February until the middle of April, there is twilight for the whole night from the early part of March until the sun ceases to set. The sun does not rise in this latitude from about October 22 until February 20, but each day there is a period of twilight which is the brightest at noon. At Trondheim (Norway) there is a bright twilight at midnight from the later part of May until the later part of July. The longer duration of twilight in the high latitudes is illustrated by above diagram.

The higher speed of the earth at the equator accounts for the shorter period of twilight there, as compared to the longer period of twilight due to slower speed in the higher latitudes. During one hour the earth covers greater distance at the equator than at latitude 60° N. At latitude 75° N. the diagram shows, that although the twilight steadily dims towards midnight rotation does not carry a place into darkness.

## SUMMARY

Thus, it is clear that the belt of maximum insolation on the earth's surface swings north and south across the equator during the year. This swing is based upon the shifting of :—

(*a*) the direct rays of the sun which determine the *intensity* of insolation ; and

(*b*) the circle of illumination which determines the *duration* of insolation.

The result is that for the year as a whole as well as on the equinoxes the highest insolation is at the equator from where it diminishes regularly towards the poles.

The causes of this swing lie in the earth's revolution round the sun, and the inclination of its axis to the plane of its orbit.

CHAPTER IV

# ATMOSPHERE (*continued*)

AIR TEMPERATURE—INVERSION OF TEMPERATURE—DIURNAL CHANGE OF TEMPERATURE—SEASONAL CHANGE OF TEMPERATURE—TEMPERATURE LAG—ISOTHERMS—GEOGRAPHICAL DISTRIBUTION OF TEMPERATURE—SUNSPOTS AND TEMPERATURE.

## Air temperature

The insolation that is received on the earth's surface is absorbed by it first. It is then converted into terrestrial energy and radiated in the form of long waves. The terrestrial energy is the *heat energy* that heats the air which is in contact with the earth's surface. The earth's surface is, therefore, to be considered as a vast heat-producing laboratory from which the atmosphere is heated. Insolation is only an *indirect source* of heat to the atmosphere, the most *direct source* being the earth's surface. This being the case, the nature of the earth's surface has a considerable influence on the heating of the air. For the different parts of the earth's surface respond differently to the insolation that is later on converted into heat energy. Land surfaces produce and radiate more heat out of the solar energy than do the water surfaces. Consequently, the land heats the air in contact with it more than water is able to do.

The different treatment that insolation receives at the land and water surfaces is of fundamental importance to the heating of the atmosphere. Land and water differ from each other in the nature of their composition. Land is solid, water is fluid and has got greater mobility. The rays of the sun that are received by land surface are concentrated in its upper layer and heat it. This heat cannot be transferred to the lower layers of the surface, as the particles composing the land surface cannot move. In the case of a water surface, a considerable proportion of the sun's rays is lost by *reflection*. For the water surfaces are much better reflectors of the sun's rays than land surfaces. So the amount of the insolation that actually remains for being converted into heat at the water surfaces is less than on the land surface. This insolation is scattered through a great depth of water.

The water masses are comparatively transparent and the sun's rays, therefore, penetrate into deeper layers than is possible in land surfaces. The heat that is produced from these rays is consequently distributed over a larger mass of water. The transmission of heat in water is further helped by the waves and currents which cause a

movement in it. Owing to all these facts, water bodies heat more slowly than land bodies. In other words the *specific heat* of water is greater than that of land. Water being formed by the combination of some gases, *evaporation* (re-conversion of water into gases) takes place as a result of heating. Evaporation, therefore, consumes a considerable amount of the heat in water. The after effect of evaporation is cooling, so that water masses are heated less also because of the continuous evaporation from them.

We find, thus, that land differs from water in being solid and, therefore, is heated more quickly and to a greater degree. The converse is also true; land cools more quickly than water.

The main process in the heating of the atmosphere is, for our purposes, the *conduction* of heat from the heated surface of the earth to the layer of the air that lies in contact with it. The heated air expands in volume and moves, leaving room for the cooler air to slide down to the heated body and be heated in its turn. The significant fact in the heating processes of the atmosphere is the freedom of the air to move. It is this movement which enables the cooler air to come into contact with a heated body and be heated. Air currents are an important feature in the heating of the atmosphere. The heated air currents pass some of their heat into space which is taken up by other layers of air. This giving out of heat is called *radiation* which is another process in the heating of air.

The heated layer of the air at the surface of the earth expands in volume and being lighter rises up. This rising layer is displaced at the surface of the earth by the cooler air which is heavier and is, therefore, settling down. When this new layer has been heated it rises in its turn, giving place to a fresh layer. A regular circulation of air currents is thus formed. These currents are called *convectional currents*, and a whole mass of air heated through their agency. It should be noted that convection will occur only when one part of the earth's surface is heated more than the other, so that there is a supply of cool air to flow in. Another method, peculiar to atmosphere, is the heating by *compression*. When air is descending, the weight of the layers above it is continually increasing. It is being pressed down by successive layers. In other words, its pressure is increasing. This increased pressure leads to the lower layers being heated.

Conversely, when air expands in volume it is cooled. The expansion of any substance requires heat, and if this heat is not supplied from an outside source, the substance becomes cooler. Consequently the ascending air becomes cooler and cooler as it ascends. The ascending air cools at the rate of about 3·6°F. for every 1,000 ft. This is about twice as much as the loss of heat due to altitude in the upper layers of the atmosphere.

Temperature of air may, therefore, change :—

either (1) because it takes up heat from other hotter bodies or gives out heat to other colder bodies,

or (2) without any transference of heat whatever, simply owing to the change of its pressure. When a mass of air is so protected that no heat can be transferred to it or taken from it while it is subjected to a change of pressure, the condition is called *adiabatic* or 'isentropic.' The temperature of rising air falls adiabatically at the rate of 5·5° per 1,000 feet.

It is difficult to find a case in nature where the two causes given above do not combine to some extent or the other.

Generally speaking, heated air rises if there is cooler air to take its place. This rise tends to limit the extent to which the surface air can be heated. In other words, there is a limit to which the maximum temperature of the air can rise. On the other hand, the surface air that is cooled locally must remain on the surface. There is, therefore, no limit to which the minimum temperature of the air can go.

The temperature of the air depends on three principal factors. These are :—

(*a*) The height of the sun above the horizon, and the duration of daylight, or, in other words, the amount of insolation.

(*b*) The character of the earth's surface.

(*c*) The transparence or opaqueness of the air.

(*a*) Ultimately, the sun is the chief source of heat. The heat that the air can get from the earth's surface depends upon the amount of insolation received there. This amount of insolation is closely related to the angle at which the sun's rays strike the earth's surface. The higher the sun is above the horizon, the more direct are the rays received. It has been discussed above how the direct rays give more heat than slanting rays. In the mornings, the sun's rays are more slanting than at noon. The temperatures are, therefore, lower in the mornings than at noon. Similarly, the rays are more direct during summers than during winters. The temperatures are, consequently, higher in summers than in winters. Within the tropics, the sun's rays fall more directly than in the higher latitudes. The result is that the temperatures are higher in the tropics than in the higher latitudes. This last fact explains why the boundaries of the thermal zones of the earth (*i.e.*, the tropics, the temperate zone, the frigid zone) follow latitudes.

(*b*) The heating of the air is, however, not a direct result of insolation. It is through the conduction and radiation of heat from

the earth's surface that the air is heated. The temperature of the air, therefore, is a product of the character of the earth's surface. The distribution of land and water naturally affects the temperature of the air. Forest areas and marshes also send to keep down air temperature. That is the reason why stations situated at the same latitude, even though they may have the same amount of insolation, do not have the same air temperature.

As the earth's surface is the *direct* source of heat for the air, the farther one rises above it, the lower is the temperature of the air, generally speaking. *Altitude*, therefore, modifies to a large extent the temperature of the air. The average decrease is about 1° F for every 330 feet.* The decrease is not, however, uniform.

Sometimes this condition is entirely reversed. There is an increase in temperature with increase in altitude. It occurs frequently on clear nights, especially during winter, owing to a rapid radiation from the ground. This condition is called the *Inversion of temperature.* In mountainous areas inversions of temperature are often caused by *air drainage*, or the flow of cold heavy air down a valley slope, thus forcing the warm air in the valley to move upward Frost is usually associated with inversions of temperature under such conditions. Inversion of temperature may also occur when a mass of warm air moves over a cold land surface. Sometimes an inversion occurs when the land is covered with snow. The air in contact with the snow surface is colder than the air at a greater height, which is far from the snow covered land.

(*c*) The atmosphere contains a certain amount of dust and water vapour. These things, especially water vapour, have a blanketing effect upon the heat that is generated at the earth's surface. They do not allow this heat to escape. Their presence or absence in large quantities in the air, therefore, has a direct bearing upon the temperature of the air. On a clear night when there are no clouds the loss of heat from the earth's surface through radiation is much quicker than on cloudy nights. Cloudy nights are warmer than clear nights on this account. The blanketing effect of the atmosphere is increased with the increase in the supply of moisture in it. It is decreased and consequently cooling of air is accelerated when the moisture supply is decreased.

That is why the cooling of the earth's surface by radiation is most rapid at elevations and in dry regions where the amount of water vapour is little.

The dust and water vapour affect not only the outgoing heat radiated from the earth's surface, but also the incoming solar energy

*According to Hann and Suering [Lehrbuch der Meteorologie, page 125] this decrease is 1°C. for the first 180 meters, 1°C. for 200 meters above that height and 1°C. for the next 250 meters. Or 3°C. for a rise of about 630 meters.

or insolation. They absorb, together with ozone, a certain amount of the incoming solar energy.

In this connection, the effect of the atmospheric disturbances (cyclones and anti-cyclones) must also be noticed. Not only do these disturbances affect the cloudiness of the atmosphere of the areas they visit and thereby alter the temperature conditions of the air, but they also lead to the flow of winds from one region to the other with differing temperatures. These 'imported' temperatures, therefore, modify the 'local' temperatures as determined by local conditions.

The temperatures of the air are, thus, the product not of any one factor, but of several factors with differing importance from place to place and from time to time.

The earth's average temperature is, however, almost constant. This is a clear proof that all the heat that is received from the sun is eventually radiated. Cooling of the earth is, therefore, as important as the heating.

### Diurnal change of temperature

Insolation is received only during the day, *i e.*, the period when the sun shines on us. Owing to the rotation of the earth, only one-half of the earth has the sun shining on it; the other half is in darkness. During the day the temperatures, therefore, rise. During the night they fall. The alternation of day and night is thus, the main cause of the daily (diurnal) change of temperature. During the morning and evening, due to the curvature of the earth's surface, the rays of the sun strike slantingly and, therefore, the temperatures are lower than at noon when the rays are more direct. This is the second cause of the daily change of temperature. The occurrence of clouds, inversion of temperature and the imported temperatures through the winds are the other causes. The last mentioned causes do not come at fixed hours and, therefore, they disturb the regularity of the daily temperature curve.

The lag in the highest (maximum) and the lowest (minimum) daily temperatures is a marked feature of the daily temperature chart. Normally, the maximum temperature should coincide with the noon-sun, as it is then that the insolation received is the highest, while the minimum temperature should be at mid-night. Actually, however, the highest temperature is recorded in the afternoon, between 2 P.M. and 4 P.M. and the lowest, just before sunrise. The reason for this lag is, of course, simple. It takes some time for the earth radiation to pass to the atmosphere. The highest temperature is, therefore, in the after-noon. Similarly the heat generated during the day is lost almost completely during the night and the lowest temperature is before sunrise. Another reason given by J. Rouch* is that temperature continues to rise as long as the amount of insolation exceeds the

*L' Atmosphere, p. 58.

radiation of heat from the earth. Radiation from the earth exceeds insolation only late in the afternoon when the downward trend of temperature begins.

Generally speaking, the following conclusions apply to the daily temperature :—

(1) The daily range (the difference between the maximum and the minimum) of temperature is more in the equatorial than in the polar regions ; it decreases from the equator towards the poles.

(2) The exposure of the place, the nature of the soil, altitude modify to a great extent the daily range of temperature.

(3) In the interior of the continents the range of temperature is greater than near the coasts. Land is heated greatly during the day and cooled greatly during the night. The air that lies over it follows suit. In the maritime regions, the specific heat of water being higher than that of land, heating and cooling are slow. Days are, therefore, not so hot and nights not so cold, as in the continental regions.

(4) Clouds, through their blanketing effect, play the same role as the sea. The range of temperature is low on cloudy days.

(5) When the ground is covered with snow or ice, the range of temperature is increased, for snow surfaces favour quick radiation.

(6) Altitude decreases the range of temperature. The range of temperature is practically nil at elevations above 4,000 feet in free atmosphere On mountains, the temperatures are influenced by the mountain mass and do not represent conditions found in the free air.

On high plateaus, however, altitude has an opposite effect to what it has in the free air. The comparatively pure air favours rapid radiation during the night and rapid heating during the day. This gives a great range of temperature.

### Seasonal change of temperature

The seasonal change of temperature is caused by the following :—

(1) The inclination of the earth's axis. This affects insolation by determining the number of day-light hours and the directness of the sun's rays.

(2) Local factors which include the distribution of land and water presence of ocean currents, the cloudiness of the atmosphere, and winds.

The following are the important featurts of the seasonal change of temperature :—

(*a*) There is little seasonal change of temperature within the tropics. For the duration of sunlight as well as the height of the

sun above the horizon undergo little change in the tropics during the year. However, the temperature is slightly higher in those months in which the sun shines overhead than in the months when it is a little below the zenith. Except on the Tropic of Cancer and the Tropic of Capricorn, throughout the tropics there are two maxima and two minima of temperature depending upon the passage of the sun, back and forth, across the equator.

(*b*) Outside the tropics, there is only one maximum and one minimum during the year. These coincide with the highest and the lowest sun above the horizon respectively. The maximum temperature occurs when not only is the sun highest above the horizon, but when the duration of the sun-light hours is also the greatest. The minimum temperature, on the other hand, occurs when the sun is the lowest above the horizon and when the sun-light hours are the least.

(*c*) The maritime places have less seasonal change of temperature than the continental interiors. The maximum and minimum temperatures at maritime places occur later than in continental interiors situated at the same latitudes.*

(*d*) Altitude also causes a diminution in the seasonal variation of temperature.

The greatest seasonal variation of temperature so far recorded is +57°C. in the Sahara, and −70°C. at Verkhoiansk in Siberia.

### Horizontal distribution of temperature

The horizontal distribution of temperature on the earth's surface is represented by *Isotherms*. Isotherms are lines of equal temperature† reduced to sea level. They are lines connecting all places which would have the same mean temperature if those places were situated at sea level. The Isothermal maps give only a *conventional picture* of the temperatures prevailing in any region. They do not, therefore, present anything real. (1) In the first place, the data from which these lines are drawn are the averages of observations recorded over a certain period of time. (2) In the second place, the temperatures are reduced to sea level, so that even the averages are not based on temperatures that have been actually observed. (3) In the third place, a particular isotherm connects not only those stations which show the temperature represented by that line, but also those places which show nearest temperatures. For these reasons it cannot be

*Thus in the northern hemisphere, the hottest month on the coast is August, even though in the continental interiors July records the highest temperature. Similarly, the coldest temperature occurs in February, though January is the coldest month for the continents.

†Air temperatures are recorded by thermometers. Observations are taken several times a day and average is struck to find the daily mean temperature. Maximum and minimum thermometers are used to record the highest and the lowest temperatures reached. Ordinarily, mercury thermometers are used, but in very cold climates where mercury freezes alcohol thermometers are used.

said that a place through which, on the map, a particular isotherm passes must necessarily have that temperature. (4) The isothermal maps, however, give a good generalised pic.ure of the tendencies of temperature distribution. In the case of tropics, where the changes are small, the isothermal maps give a fairly accurate idea of the actual conditions, but in the temperate regions where the fluctuations in temperature are great, these maps do not give a correct idea.

The general characteristics of the mean annual isothermal maps are the following :—

(1) The isotherms run east-west, generally following the direction of the latitudes. This is due to the fact that temperature depends upon insolation which closely follows the latitudes. This shows that latitude is the greatest single cause of temperature contrasts on the earth's surface.

(2) The east-west trend of isotherms in the southern hemisphere is more marked than in the northern hemisphere. This is because the mass of water predominates in the southern hemisphere ; while in the northern hemisphere land, with its diversified surface, dominates.

(3) Where land and water meet there is a devi tion from this east-west trend of isotherm. This deviation is caused by the differences in the heating and cooling capacities of land and water. There is some effect of the ocean currents also on this deviation.

(4) Tnere is a marked poleward bending over the North Atlantic and the North Pacific, owing to the warning effect of the Gulf drift and the Kuro Siwo.

(5) Similarly, there is a marked equatorward bending of the isotherms, owing to the cold currents. These cold currents are the Labrador current on the east coast of Canada. the California current on the Californian coast of North America, the Benguela current on the west coast of Africa and the Humboldt current on the west coast of South America.

(6) The highest average annual temperatures are in the tropics and the lowest in the polar regions. The thermal equator* passes through the tropics.

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*A line drawn completely around the world through the axis of the highest annual temperature is called the 'Thermal Equator' to distinguish it from the Geographical Equator. This is the line along which the highest mean annual temperature is found. The thermal equator shifts north or south of the geographical equator according to the position of the sun.

Otto Terens prefers to use the term "meteorological equator" for the "thermal or heat equator" for the dividing line between northern and southern temperature regimes or between the regions with the January and the July half-years the colder. Where January and July temperatures are equal you have the meteorological equator. For a more exact determination the temperatures of the half-years centring on February 1 and August 1 should be compared. The meteorological equator lies about 1 degree north of a great circle cutting the geographical equator at an angle of 5 degrees at longitude 90e and reaching farthest north on the Greenwich meridian and farthest south at 180 degrees.

## January and July Isotherms

The Perihelion and the Aphelion positions of the earth falling in January and July respectively, the temperatures for these months, for the earth as a whole, represent seasonal extremes.

January is the coldest month in the northern hemisphere, and hottest in the southern hemisphere. The coldest temperatures in the northern hemisphere are on land. Three areas that record the coldest temperature are :—(1) Verkhoiansk* in Siberia with 50°F, (2) Greenland, with 30°F., and (3) the islands north of Canada with —30 F. The poleward bend of the isotherms on the oceans due to the influence of the warm ocean currents and the equatorward bend on land masses owing to the differential cooling of land and water are very much prominent in the January map.

On the map, on page 60, the northern hemisphere shows a crowding of the isotherms as compared with southern hemisphere, or the July map. This crowding is, however, marked only in the middle latitudes on lands. Further north or sourh of these latitude, the isotherms are situated far apart This shows that the temperature gradient is steep in the middle latitude continents in winter. These steep gradients are largely the result of the atmospheric disturbances (cyclones and anticyclones) which are prevalent during winter in the middle latitudes of the northern hemisphere.

In the southern hemisphere, there are in January three areas of maximum temperature. These areas are on the three southern continents ; of these Australia and Africa being more marked than South America.

The July map (p. 61) shows a considerable latitudinal shifting of temperatures to the north. The bends of the isotherms in the January map (p. 60) are found reversed in the July map. The isotherms on the oceans to the northern hemisphere bend equatorward, while those on land bend pole-ward. This is because, in the northern hemisphere, land is heated more than water at this time. The highest temperatures are found in the desert and semi-desert areas of the

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*Since the seventies of the last century, Cold Pole has been placed at Verkhoiansk, on the Yana River in north-eastern Siberia. Professor Obruchev in 1926 expressed his opinion that still lower temperature in winter might prevail at the settlement of Oimekon on the Indigirka some 650 km. south-east of Verkhoiansk. Observations carried out by the Soviet Academy of Sciences from 1929-1934, have confirmed this view.

In eastern Siberia, decrease in temperature accompanies increase in altitude during the summer only. In winter reverse is the case owing to the downward flow of masses of exclusively cold air. Air drainage of this type proceeds unhindered because of the almost perfect calm that prevails over N.-E. Asia.

Verknoiansk and Oimekon both lie in basins surrounded by almost unbroken mountain ranges. The accumulation of cold air in these basins accounts for the extraordinary low temperature.

northern hemisphere. South-western Asia, North Africa and Western North America show the highest temperatures.

In the southern hemisphere, owing to the prevalence of water, the isotherms run straight.

A map (p. 62) showing the minimum temperatures is very much like the map showing the mean annual temperatures. There

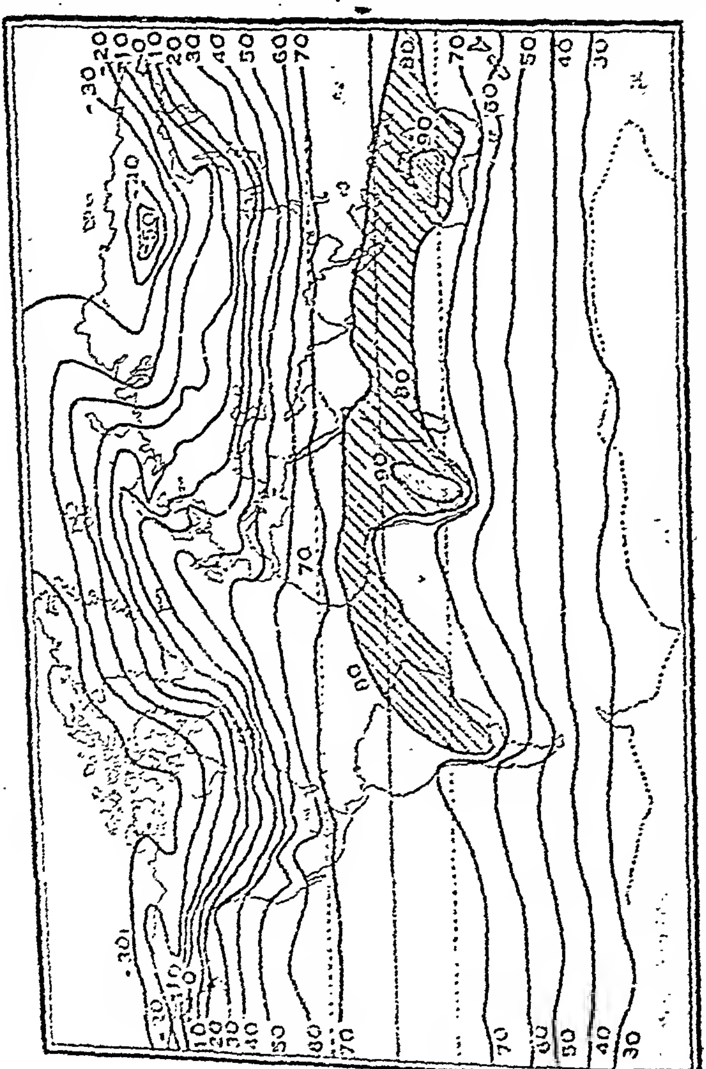

Fig. 22. Isotherms For January. Shaded Parts Show Highest Temperatures.

are two areas, in which the minimum temperature never goes below 20°C. The more important of these areas is the one extending from Arabia to New Guinea. As one proceeds further and further to the north from this area, the minimum temperature recorded becomes lower and lower. The lowest temperatures recorded are in Siberia, Greenland and North-West Canada. The

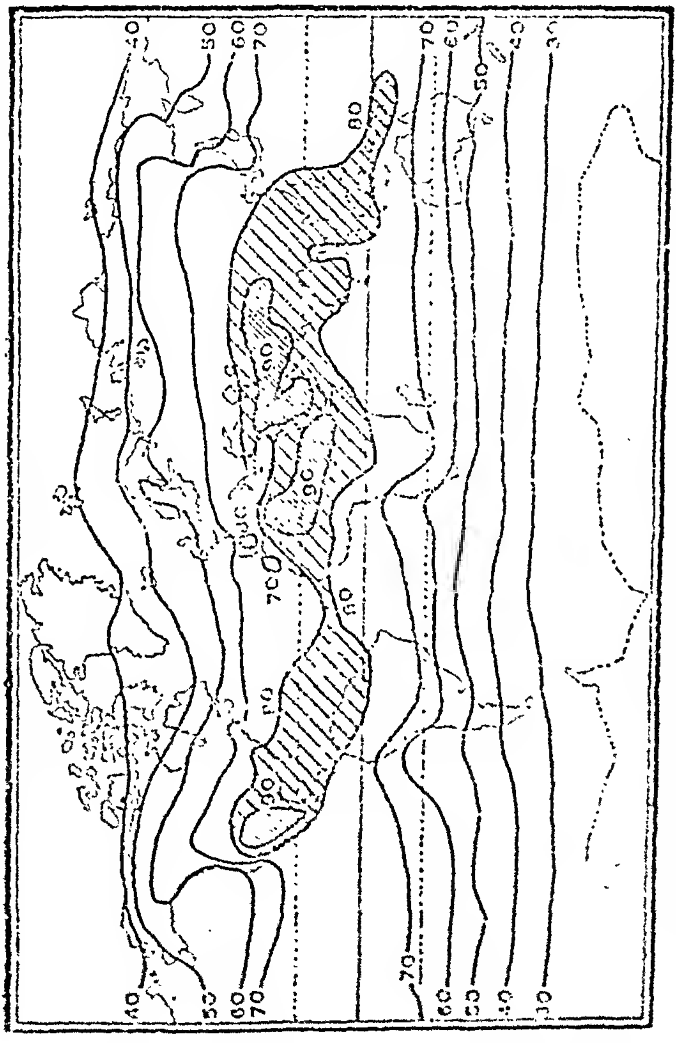

Fig. 13. Isotherms For July. Shaded Parts Show Highest Temperatures.

minimum temperature recorded in the southern hemisphere are not so low as those in the northern hemisphere. The *equatorward* bend of the isotherms showing minimum temperatures on land is a clear proof of the greater cooling to which land is subjected. This bend is very conspicuous in the case of the 32°F. isotherm passing through South America and Australia.

The highest maximum temperatures are marked in the continental interiors in the low latitudes. The largest areas of the highest maximum temperatures are:—(1) Africa, Arabia and North-West India; (2) Australia; (3) Western part of North America; and (4) Argentina.

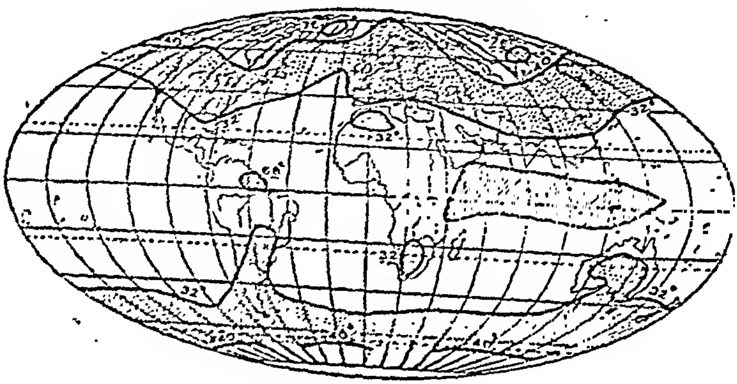

Fig. 24. Showing Minimum Temperature in 0°F.

The Greeks divided the earth into thermal zones. These zones were:—(1) Torrid Zone, (2) Temperate Zone, and (3) Frigid Zone. The boundaries of these zones were fixed by latitudes, and not by isotherms. Supan has, however, fixed the boundaries of these zones by isotherms. In his division, the mean annual isotherm of 68°F. separates the Torrid Zone from the Temperate Zones, and the 50°F. isotherm for the *hottest month* separates the Temperate Zones from the Frigid Zones. The following map shows this division:—

## Temperature as a whole equable

The earth temperatures remain more or less the same from year to year, owing to the following factors:—

(1) The eccentricity of the earth's orbit is so slight that the farthest and the nearest points on this orbit make only slight difference in the amount of solar energy. The earth receives only 7 per cent more energy in its nearest position to the sun than it gets in its farthest position.

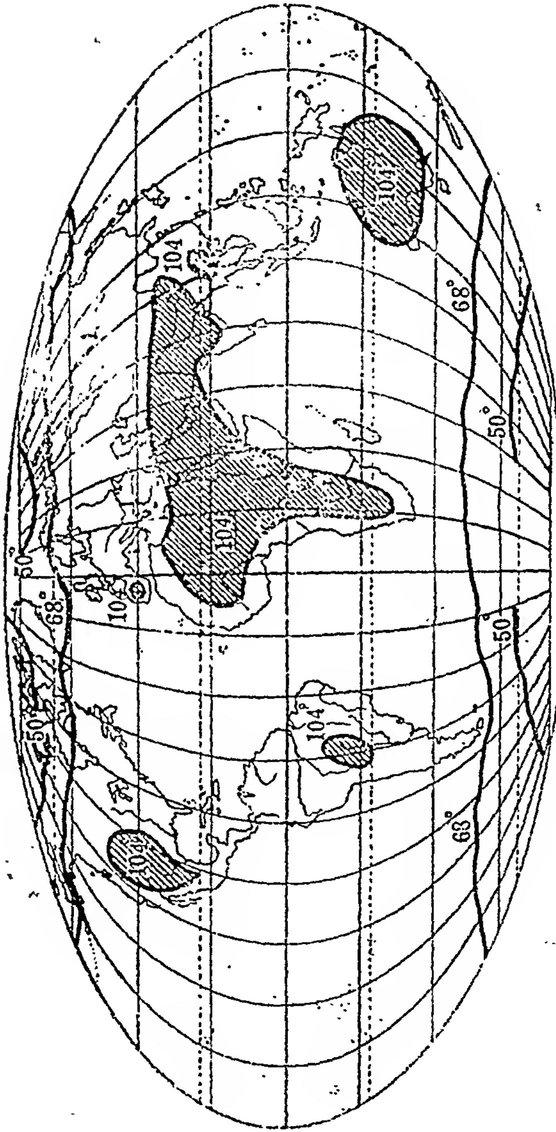


Fig. 25. Showing Maximum Temperature in o°F.

(2) The succession of night after day and summer after winter prevents the temperatures from being continuously too hot or too cold. The greater heat received during the day is lost during the night. By the time the earth's surface has cooled down sufficiently during the night, the day dawns again and the temperature rises and the lost heat is recouped.

(3) The blanketing or greenhouse effect of the atmosphere is another factor which prevents the existence of extreme temperatures on the earth's surface. The atmosphere is diathermaneous [transparent] to radiations from a very hot source like the sun, as they are of short wavelength, but it is athermaneous [opaque] to heat radiated from a low temperature source like the earth, as these radiations are of long wavelength. As a result the atmosphere prevents too much loss of heat at night. The heat lost from the earth's surface would greatly exceed the heat received from the sun were it not for this blanketing effect of the atmosphere.

(4) The cycle of seasons also helps in maintaining equable temperatures. The alternate heating and cooling of each hemisphere, which results from the fact that the axis of the earth is inclined and always points in one direction, allows each hemisphere to have equable temperatures.

(5) Winds and ocean currents militate against extreme temperatures, by bringing about a mixing. Upto 40° latitude the earth records a net gain of heat annually, while beyond 40°, the earth records a net loss of heat. The winds and ocean currents transport heat from regions with a net gain of insolation to regions with a net loss. It has been calculated that 13,600 billion kelonjoules of energy is transported by these agents every second.

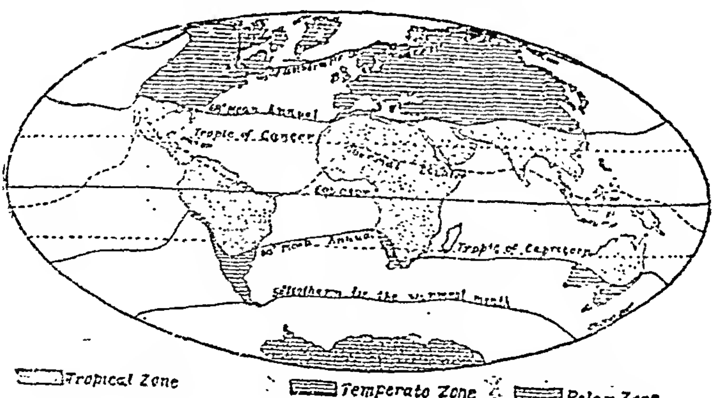


Fig. 26. Showing Thermal Zones [After Supan].

(6) The distribution of land and water on the earth's surface with their differential treatment of heat, also tends to maintain a balance between the heat and cold on the earth. Water tends to modify the land temperatures because of its specific heat.

## Sunspots and temperature

Solar radiation increases and decreases according to the number of sunspots.*

As long ago as 1651, Father Riccioli, a Jesuit priest, announced that when sunspots are numerous the temperature of the earth's surface falls, while it rises when the sunspots are few. This conclusion was confirmed by Herschel, a great astronomer, in 1801. There was, however, a great controversy over this question until the final tabulations of Koepen, published in 1934, set it at rest. These tabulations showed that the temperature of the earth as a whole falls when sunspots increase and *rises* when they decrease.

The measurements of the solar radiation made by Abbot and others clearly show that the sun emits more energy when the sunspots are numerous than when they are few. This establishes the fact that *warmer the sun, cooler the earth.*

Several explanations are suggested for this fact. These explanations are :—

(1) The increased evaporation at the time of the maximum sunspots causes increased cloudiness and thus shuts out the sun's heat, thereby lowering the surface temperature on the earth.

(2) The oceanic circulation is so altered that more cold water wells up from beneath and thus the temperature of the surface is lowered

(3) The supply of ozone in the earth's atmosphere increases when the sunspots are few. This ozone acts as a blanket to keep the earth warm at the times of few sunspots. The case is reversed when the sunspots are numerous.

(4) At the time of the maximum spots, some changes take place in the upper atmosphere. This causes corresponding changes in the winds and in the temperatures on the earth's surface. Relatively warm air is transferred bodily from the surface to the upper air, and thus the earth's surface is left cooler.

The following map shows the relation between solar radiation and temperature :—

*The bright surface of the sun is called the photosphere. On this bright surface, here and there, are a few more brilliant areas called 'faculae' and few darker areas called 'sunspots.' These sunspots are great vertices in the atmosphere of the sun, revolving sometimes in one direction and sometimes in the other.

5

Clayton* has studied the influence of sunspots and the solar radiation on the earth's weather. His conclusions about the shorter period (five-day average) are that, in a general way, there is a tendency within the tropics for the temperature to increase and decrease with solar radiation; but with a slight lag. In the intermediate zone,

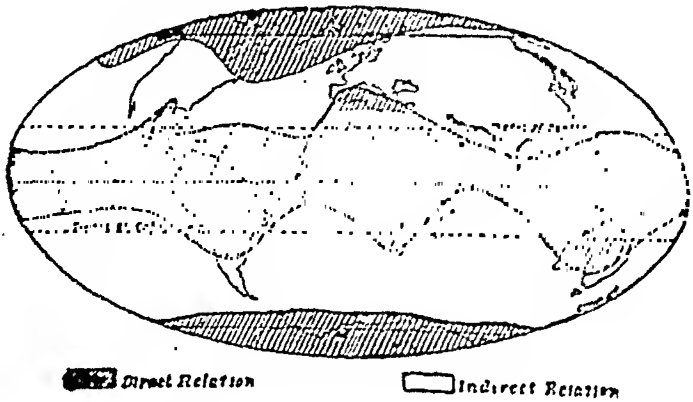


Fig. 27. Sunspots and Temperature.

from 30° to 60°N, on the other hand, there is an inversion; the temperature fell as the solar radiation increased. In the higher latitudes, from 60° to 70°, the relation between temperature and radiation was again direct.

*H. Clayton: *World Weather*, 1923.

CHAPTER V

# ATMOSPHERE—(*continued*)

PRESSURE AND CIRCULATION—BAROMETRIC TIDE—SEASONAL VARIATION OF PRESSURE—JULY AND JANUARY PRESSURE—ISOBARS—ISALLOBARS—WIND —GEOSTROPHIC WINDS—GRADIENT WINDS—PLANETARY WINDS—DOLDRUM—TRADE WINDS—WESTERLIES—MONSOONS—LAND AND SEA BREEZES—MOUNTAIN AND VALLEY BREEZES—FOEHN—MISTRAL—BORA—WIND OBSERVATION.

## Air pressure and circulation

The atmosphere is characterized by a great mobility, owing to the nature of its composition. It consists of a number of gases and water vapour which can move freely in any direction even at the slightest change in the given conditions. This mobility alters the amount or the density of air existing at any place or at any time. The earth is supposed to be covered with interconnected columns of air which rise vertically to great heights. Air can freely pass, however, from one column to the other at any height. The transfer from one column to the other causes a change in their density. This density may be called the pressure of air in these columns resting on the earth's surface.

It is known that heat applied to atmosphere causes it to expand and to rise. The rising air reduces the pressure in the column of air that is heated and from which it is rising. The rising air has a tendency to flow aloft into the adjoining column at the slightest opportunity. The flow of air into another column, therefore, increases its pressure or weight. Thus, the application of heat to one column of air has resulted in the reduction of pressure in that column and increase of pressure in the adjacent column. We find, therefore, on the earth's surface, that wherever there are high temperatures the air pressure is low, and by the side of it where the temperatures are lower, the pressure is high. Low air pressure and high air pressure, thus, exist side by side.

It has been estimated that every inch of the ground at sea level supports a column of air that is several hundred miles tall, but whose weight is only about 15 lbs. Most of this weight is in the lower parts of the column. If you rise 17,500 feet above the sea level, half of the weight of the whole atmosphere in that column will lie below you. Pressure of air, therefore, *decreases* not only as you move from cooler to *hotter areas* on the earth's surface, but also as you move *upwards*. The concentration of the greater part of the

atmosphere in the lower regions is caused by the force of gravitation. So that the upward decrease of pressure* is due to a dynamic cause.

We find, therefore, that changes in the pressure of the earth's atmosphere are due to (a) thermal causes and (b) to dynamic causes.

There are seven distinctly marked pressure belts on the surface of the earth. These are shown in the following diagram :—

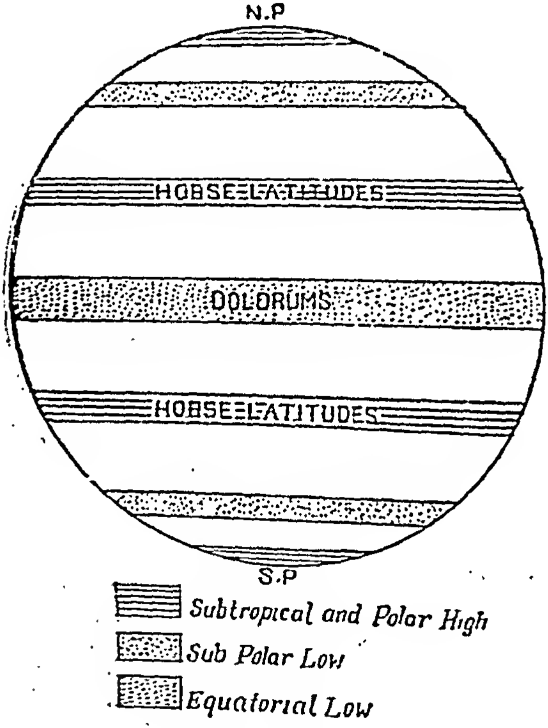


Fig. 28. Pressure Belts.

The low pressure belt at the equator is due to the high temperatures found in equatorial region. It is a thermally induced belt. In the higher latitudes two tendencies operate. There is the ten-

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* Air pressure is measured in millibars. 1,000 millibars represent approximately the atmospheric pressure at sea level. This pressure is also expressed in inches, for a column of mercury about 30 inches long balances the weight of the column of air covering 1 sq. inch of the surface at sea level. Pressure given in millibars can be converted into inches at the following rate :—

1,000 mb.—29·53 inches.

or

30 inches—1,015·9 mb.

dency to high pressure due to the low temperatures. There is also the tendency to low pressure which follows from the fact that the rotation of the earth causes the air in the higher latitudes to bank towards the equator. At the poles the thermal tendency to high pressure dominates and a high pressure belt occurs. The south pole is situated on an elevated, ice-covered continent, the Antarctica. There is, therefore, a permanent high pressure at the south pole. The north pole is situated in the midst of an ocean, the Arctic ocean, which is covered by ice-floes for most of the year. The Arctic ocean is, however, surrounded by big land masses of Eurasia and North America. Some of these land masses, *e.g.*, Greenland, are covered by thick sheets of permanent ice. These land areas develop higher pressure specially during winter, than the north pole itself which is situated in the ocean.

But about 60°N the dynamic tendency to low pressure is stronger than the thermal tendency to low pressure, because the temperatures are not as low as at the poles, and therefore, the sub-polar low pressure belt occurs. Other causes which bring about this belt are the rapid poleward decline of pressure from the sub-tropical highs, and the contact between land and water. The sub-polar low is prominent only on the sea, in the North Atlantic around Iceland and in the North Pacific around the Aleutian Islands in the northern hemisphere, and in the seas around the Antarctica in the southern hemisphere. The sub-polar low in the southern hemisphere is deeper and more permanent and continuous than the sub-polar low of the northern hemisphere which is shallow and broken.

The air that rises at the equator, flows aloft towards the poles. As it flows towards the poles it is deflected due to the earth's rotation. When it reaches latitudes 30° to 35° it has been deflected 90°. This is the maximum deflection possible for otherwise the wind will blow against the isobars. As the wind has been deflected 90° it cannot proceed any further polewards and is piled up in these latitudes creating a high pressure belt. Thus this pressure belt is due to a dynamic cause.

There is a close relationship between temperature and the pressure of the air. Higher temperatures cause low pressure, while the lower temperatures cause high pressure. In other words, *higher the thermometer, lower the barometer* and *vice versa*. As the temperature changes from day to day and season to season, the air pressure also varies. In the tropics, the barometer registers two maxima and two minima of pressure. The barometer rises from 4 o'clock in the morning to 10 o'clock and again from 4 o'clock in the afternoon to 10 at night. It falls from 10 A.M. to 4 P.M. and again from 10 P.M. to 4 A.M. The maximum of the forenoon is more marked than the maximum in the afternoon, and the minimum in the afternoon is more marked than the minimum in the forenoon That is to say,

the higher rise of the forenoon is balanced by the greater fall of the afternoon. The barometric maxima and minima are called the *barometric tide.* The following diagram shows the daily variation of the barometer :—

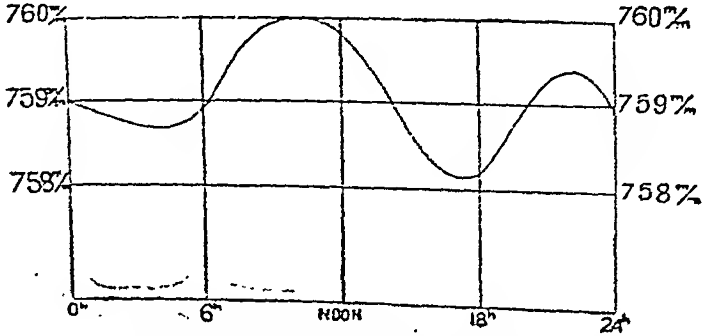


Fig. 29. Daily Barometric Variation or Barometric Tide.

As one proceeds away from the equator, the barometric tide diminishes in amplitude, though it is still apparent as far as 60° north and south.

The forenoon maximum and the afternoon minimum are much more marked in the continental interiors than in the maritime regions where the temperature contrasts are not so large during the day. On the other hand, the night maximum and the early morning minimum are more marked in the maritime places than in the continental interiors.

At stations, situated on the mountains, the pressure conditions are reverse of the pressure at the plains. When there is a low pressure at the plains, the mountains have a high pressure. The air that rises from the plains goes to increase the supply of the air at the mountains. This causes an increase in the air pressure. Similarly, when the plains have a high pressure, the air from the mountains is pressing down and leaving the mountains, causing a low pressure there.

At higher altitudes, the daily variation of pressure is not much marked.

## Seasonal variation of pressure

The monthly changes in the pressure within the tropics are small, far the temperature changes there are insignificant. Whatever changes occur in the pressure within the tropics, however, are due to the changes in temperature.

The most marked feature of the seasonal distribution of pressure is that the pressure system follows the highest sun. *In other* words, the pressure system of the earth is tied to the temperature regime. So that not only has the highest sun an intimate relation with the pressure distribution, but also the distribution of land and water through its effect on temperatures modifies it. High pressure, therefore, occurs where the temperatures are low, and low pressure where the temperatures are high.

An important feature of the seasonal changes in the pressure distribution in the northern hemisphere is that, owing to the predominance of land in this hemisphere, the normal pressure belts mentioned above on page 68 are considerably modified. During summer when the sun is shining overhead in the northern hemisphere, the land mass of Eurasia becomes so heated that the belt of subtropical high practically disappears on this land mass. During winter, on the other hand, owing to the unusual cooling of this land mass, the high pressure covers practically the whole of the interior. The pressure belts are, thus, broken into a number of *seasonal centres* of low and high pressure, rather than continuous belts.

In January, the highest pressure (778 mm.) is in Central Asia. Other centres of high pressure are in the Atlantic ocean, about the latitude 30° N., and in the Pacific ocean, west of California. In the southern hemisphere, the high pressure areas are, in the Pacific, west of Chile; in the Atlantic, west of south Africa; and in the Indian Ocean, west of Australia.

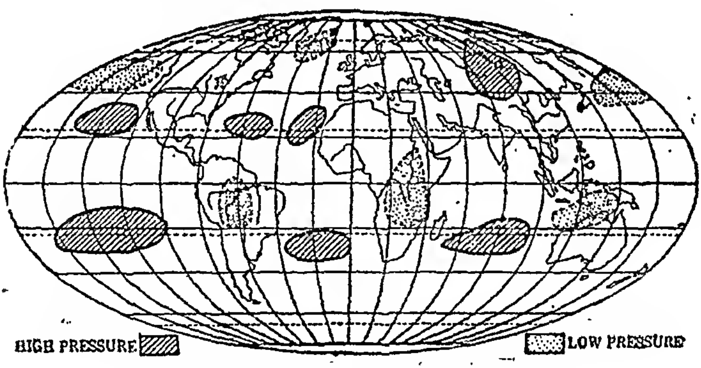


Fig. 30. Showing Mean Pressure for January.

The lowest pressure is found in the Antarctic region (740 mm.). The largest area under low pressure is, however, within the tropics. Other areas of low pressure are near Iceland in the North Atlantic, and near the Aleutian Island in the North Pacific.

In July, there is a general increase of pressure in the southern hemisphere where in the neighbourhood of 30°S. the pressure reaches about 767 mm. High pressure also exists in the North Atlantic, near the Azores Island, and in the Pacific. These high pressure centres belong to the general belt of the sub-tropical high pressure.

Low pressure is found generally in the northern hemisphere in this month. The most marked area of low pressure is in Central Asia where the pressure is 746 mm. Other areas of low pressure are near Iceland, in North America, in Spain and in the Po valley.

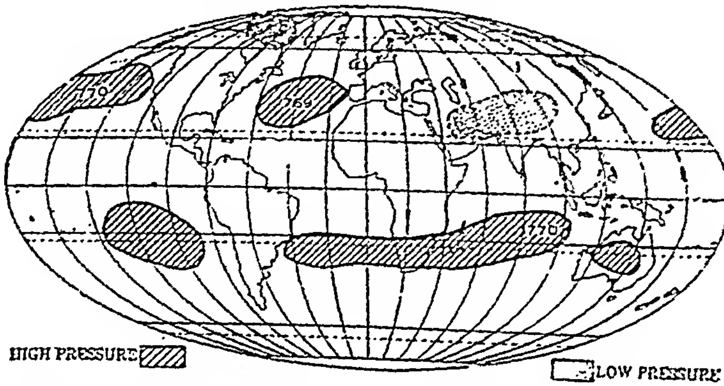


Fig. 31. Mean Pressure for July, Figures Showing Pressure in mm.

The difference between the highest and the lowest pressures in Asia, that is to say, the difference between the January and the July pressure is very great. It comes to about 30 mm.

The pressures on land and sea bring inverse, the low pressure occurring near the Aleutian Island in winter almost completely disappears during July.

## Isobars

The distribution of air pressure on the surface of the earth is shown on the map by Isobars. Isobars are the line joining places of equal pressure. As in the case of isotherms, before drawing the isobars, the records of air pressure are reduced to the sea-level pressure. It is known that a square inch of the surface at sea level supports a column of air which extends to the outer limit of the atmosphere. This column weighs about 15 lbs. at sea level. If the weight of the same column were to be taken at a height of 5,000 feet above sea level it will be only 12 lbs. If, therefore, corrections were not made to the pressure date to sea level, the difference in the pressure readings at the several places would be mucn more, largely due to the differences in their heights than to differences in the mete-orological conditions.

Lines joining places which have the same amount of change in the pressure during the last three hours are called *isallobars.* Of late, the use of isallobars in weather forecasting has become very common.

## Winds

There is a tendency with all the fluid bodies to make up the inequalities of pressure. Matter, therefore, begins to flow from the regions of high pressure to regions of low pressure. In atmosphere, the flow of air from the high pressure to the low pressure is called the 'wind'. The word 'wind' is, however, reserved for describin the horizontal flow of air only and not the vertical flow, for which latter the word "current" is commonly used.

The direction in which the pressure of the air decreases is known as the *barometric slope.* The wind starts to blow in the direction of this slope. The rate of the change of pressure as shown by the isobars is called the *pressure gradient.* It is this pressure gradient that originally determines the speed at which the wind blows. Where the isobars are crowded together in a short 'space', the gradient is said to be 'steep', and where they are spaced far apart, the gradient is 'slight'. The velocity of the wind is great when the gradient is steep.

The direction of the wind is, however, modified by the rotation of the earth. According to the law discovered by Ferrel, *all moving bodies in the northern hemisphere are deflected to their right, and to their left in the southern hemisphere.* This deflection is less near the equator than near the poles. Owing to this deflection, air from the high pressure cannot flow straight into the low pressure. It flows spirally round the low pressure anti-clockwise in the northern hemisphere and clockwise in the southern hemisphere. The surface winds blow in a direction that makes an angle of 10° to 30° with the isobars towards the low pressure. At elevations, the winds blow in a direction parallel to the isobars.

According to Buys Ballots* law the low pressure lies to the left of the wind direction in the northern hemisphere, and to the right in the southern hemisphere. That is to say, if we stand with our back to the wind in the northern hemisphere, pressure is lower on our left. In the southern hemisphere the low pressure is to our right.

When the wind is deflected owing to the earth's rotation it is called the *geostrophic wind.* Where, on the other hand, there is no deflection and the wind can follow the direction of the barometric slope, it is called the *gradient wind.* Near the equator the wind is a gradient wind. As the gradient wind moves forward the force of the high pressure at the back tremendously increases is velocity, is that

*Professor Buys Ballots of Utretcht enunciated this law in 1857.

very soon the low pressure is filled up and the wind disappears leaving a 'calm.'

The following table shows to what extent the wind velocity as determined by the pressure gradient is reduced by the deflection caused by the earth's rotation :—

*Geostrophic Wind Velocity. (Miles Per Hour)*

| Latitude | Miles between consecutive isobars indicating pressure gradient | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 60 | 80 | 100 |
| Equator | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| 10° | ... | ... | ... | ... | ... | ... | ... | 147 | 110 | 88 |
| 20° | ... | ... | 149 | 128 | 112 | 99 | 89 | 74 | 56 | 45 |
| 30° | ... | 122 | 102 | 87 | 76 | 68 | 61 | 51 | 38 | 30 |
| 40° | 119 | 95 | 79 | 68 | 59 | 53 | 48 | 40 | 30 | 24 |
| 50° | 100 | 80 | 66 | 57 | 50 | 44 | 40 | 33 | 25 | 20 |
| 60° | 88 | 71 | 59 | 50 | 44 | 39 | 35 | 29 | 22 | 18 |
| 70° | 81 | 65 | 54 | 46 | 41 | 36 | 32 | 27 | 20 | 16 |
| 80° | 78 | 62 | 52 | 44 | 39 | 34 | 31 | 26 | 19 | 16 |

[From 'Weather Map' published by the Meteorological Office, London]

The following points regarding geostrophic winds are noticeable from the above table :—

(1) The pressure gradients are very slight in the equatorial regions. Upto 10° from the equator the isobars are separated by 60 miles or more.

Even these slight gradients, however, give much higher velocity to winds owing to the absence of deflection in the equatorial regions. Compare the velocity in the last column of the same wind at latitudes 10° and 80°. At 80° it is only 16 miles per hour, while at 10° the velocity is 88 miles per hour.

(2) Velocity of the wind increases as the gradient increases. Note the increase from right to left of the table. At Puri (situated at 20°N) the wind velocity will be 45 miles per hour only when the gradient is slight, and 149 miles per hour when the gradient is steep.

(3) The wind velocity increases as one proceeds away from the poles towards the equator, and as the gradient becomes steeper.

Planetary systems of winds

Winds are related to pressure system. On the surface of the earth, the distribution of pressure systems follows certain lines deter-

mined by temperature. To each of these pressure systems (see Fig. 32) is tied a particular wind system. From the sub-tropical HIGHS blow towards the equator the Trade Winds and towards the poles the Westerlies. From the polar HIGHS blow the North-Easterlies in the northern hemisphere and South East rlies in the southern hemisphere.

The diagrammatic representation of the planetary winds is given below.

There is a considerable north-south latitudinal shift of the wind systems, as the sun marches north or south of the equator. There

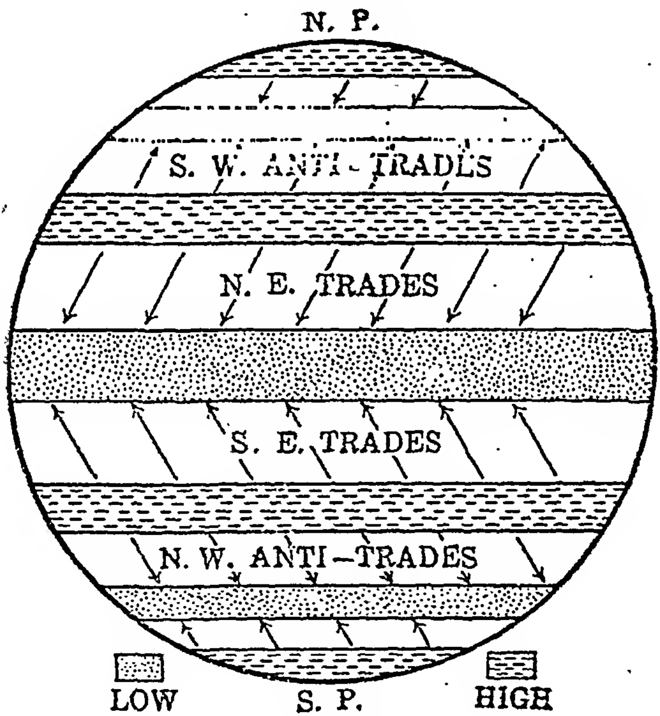


Fig. 32. Planetary Winds

are, therefore, certain parts of the earth which are transitional be-tween two wind systems. When the sun is shining overhead in the northern hemisphere, these transitional areas are covered by one wind system. But when the sun shines overhead in the southern

hemisphere and the whole of the wind system has shifted to the south, these areas are covered by another wind system which lies adjacent to the system prevailing before.

Due to the predominance of land in the northern hemisphere, the effect of seasonal variation in temperature, and therefore in pressure, is very much marked. During summer the high pressure belt in the northern hemisphere is disrupted while during winter it is greatly intensified. The effect of this is a considerable modification of the prevailing winds in the northern hemisphere.

The following diagram illustrates the seasonal modification and the latitudinal shifting of the wind systems :—

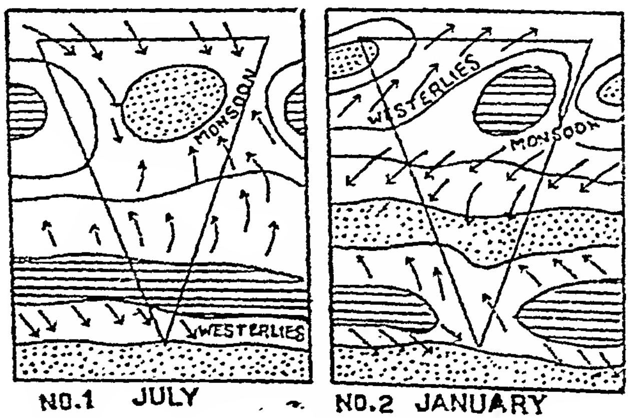


Fig. 33. Dots represent Low Pressure and Lines High Pressure. [After Hettner.]

In the above diagram the triangles represent the land mass and the rest ocean. In July, when the sun is overhead in the northern hemisphere, the pressure and wind systems are shifted slightly to the north. The sub-tropical high has disappeared entirely from land in the northern hemisphere and a low pressure centre has developed in its place. The equatorial doldrum has now become continuous with the low pressure developed on land and the sub-polar low pressure. The sub-tropical high is found only on the sea. The pressure and wind systems of the southern hemisphere, however, remain undisturbed. The north-east trade winds have practically disappeared. They are found only on a small area in the Atlantic. Towards the east, their place has been taken by monsoons which are now of an entirely opposite character to the trade winds.

In January, the sun shifts to the southern hemisphere, and with it go the pressure and wind systems. The conditions are reversed

in the northern hemisphere from that they were in July. The sub-tropical high is intensified and extended over the land in the northern hemisphere. The trade winds show an unbroken belt in this hemisphere. The low pressure centres on the oceans in the northern hemisphere are much more intensified than in summer.

In the southern hemisphere, the heated land causes a break in the sub-tropical high there. The continuity of the trade winds is, therefore, broken here.

It should be clear from the preceding discussion that the belts of the pressure as shown in Fig. 28 on page 68 seldom exist as continuous belts. They are broken into *centres of action*. It is round these centres of action that most of the wind systems of the earth circulate.

The wind systems and the doldrums where the winds are few, light and variable have been shown in the diagram on page 75.

## Doldrum or Equatorial Calm

A belt of low pressure occupies an intermediate position between the two sub-tropical highs. Except for a slight daily change, the pressure in this belt remains practically uniform and the pressure gradient is almost *nil* or very slight. Owing to this absence of gradient, the winds are weak and variable, while the calms are frequent. According to Trewartha, calms prevail in the doldrums for about one-third of the time. This belt of calms does not have a fixed boundary north or south of the equater. The position and the extent of this belt differs according to the season. In February and March it is almost at the equator and is limited in breadth ; in July and August, on the other hand, it has moved to the north up to about 7° or 8° north of the equator and covers a very large area. Most of the doldrum belt generally lies between 5°N. and 5°S. of the equator. It is developed most in the Atlantic and the Pacific oceans. In the western parts of these oceans this belt generally merges in the trade wind belt.

## Sub-Tropical Calms

Between the trade winds and the westerlies on both sides of the equator lie two belts where the conditions are more or less similar to those prevailing in the doldrums as regards winds. The air is descending here and consequently there is very little pressure gradient here. The winds that blow are, therefore, light and variable. Owing to the descending air, however, the weather is characteristically dry and fine. In this respect the sub-tropical belts of calms present a contrast to the doldrums where, due to ascending atmosphere, the weather is characteristically wet and cloudy.

The sub-tropical belts of calms are also characterised by changes in the pressure now and then, owing to the passage of storms which are so common in the belt of the westerlies lying at the boundary of these belts. These calms, therefore, are not persistent like the doldrums. The sub-tropical belts of calms are also known as the 'Horse latitudes'*, particularly in the southern hemisphere.

## Trade winds

At the equatorward margins of the sub-tropical highs are born the winds that are known as the trade winds, a name given by the sailors, owing to their constancy and regularity. In the northern hemisphere they are called N. E. Trade Winds and in the southern hemisphere S. E. Trade Winds. Their limits vary according to the variation in the limit of the sub-tropical highs themselves. Roughly, however, their extent is from 30° or 35° to 10° or 5° on both sides of the equator. The trade winds attain their greatest development in the South Atlantic and in the southern parts of the Indian ocean. Everywhere, they are more active during winter than during summer. Their velocity is, usually, not great, only about 10 to 15 miles per hour. Summer monsoons weaken them in southern and south-eastern Asia. Trade winds are seldom distributed by cyclones, and are characterised by fine weather.

## The weserlies

The Westerlies start at the poleward margins of the sub-tropical highs. The westerlies are distinct from other wind systems in that they blow from warmer regions to cooler regions. All other wind systems blow from cooler regions to warmer regions.

They extend from about 35° to about the polar circle (the Arctic or the Antarctic Circle] on both sides of the equator. No other wind system is so disturbed by storms and turbulence as the westerlies. This turbulence is marked to a greater extent toward the polar boundary than toward the tropics. The poleward boundary of the westerlies is often invaded by the surges of cold polar winds. It is here that the line of discontinuity between the warm

†This name was given to the calms in the southern hemisphere by some Englishmen who had to throw the horses, that they were carrying, into the sea for want of drinking water as their ships were becalmed.

†In some books on Geography the word Anti Trade Wind is used for the werterlies. This use is wrong. Anti-trade wind is used to describe the *upper air current* moving from the equator towards the tropics against the trade winds. It is this anti-trade wind which descends ultimately in tropical high pressure.

equtorial air and the cold polar air, known as the Polar Front, is found. The westerlies are marked by extremes: sometimes they blow with very little speed; at other times they blow with gale force.

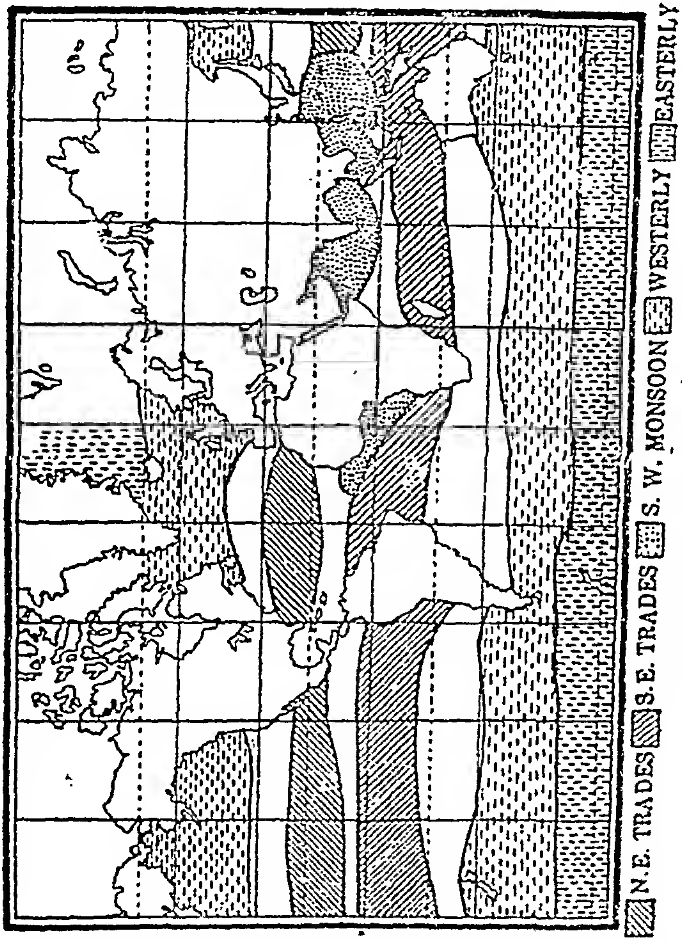


Fig. 34. Atmospheric Circulation for July.

The gale force is more common in the southern hemisphere where the predominance of the sea with its uniform surface with no obstructions, favours great velocities. The name of 'Roaring Forties' is given to these winds in the southern hemisphere. Even though they are described as 'Westerlies,' they blow from all points of the compass. This is particularly so in the northern hemisphere.

## Monsoons

The planetary wind systems of the earth are modified in some cases to a very large extent by the marked seasonal changes in the pressure distributions, due to the unequal heating of land and water. The monsoon winds are the most important example of this terrestrial modification of the planetary winds.

"Monsoon is a flow of air, directly associated with the northward or southward swinging of the great air streams—the trades

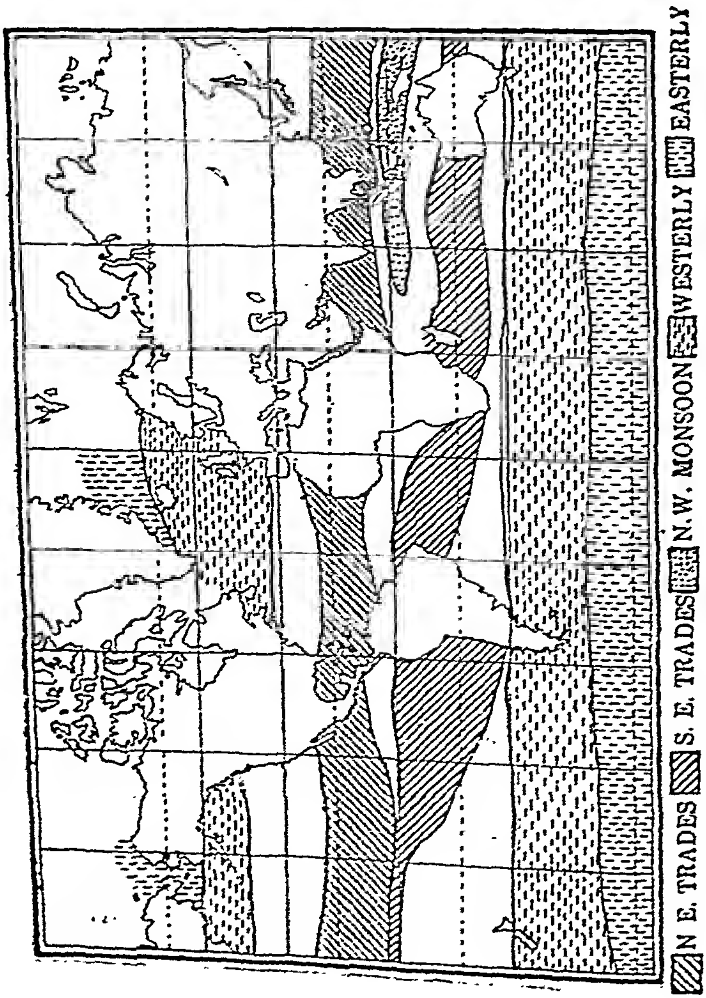


Fig. 35. Atmospheric Circulation for January.

and the westerlies".* This swinging is caused by the north or the south migration of the sun. The northward migration of the sun results in an extraordinary heating of the big land mass of Eurasia. The oceans which are cool in comparison to land, develop high pressure, and the pressure gradient from the ocean to the land becomes steep. This condition is more marked in the southern, south-eastern and eastern parts of Asia than in any other part of the northern hemisphere. The trade winds blowing normally in this part of the world are, therefore, suppressed and the flow of air from the ocean towards land takes their place. This flow is called the south-west monsoon.

During winter, the conditions are reversed, and the continental land mass of Eurasia becomes the centre of a very high pressure. The pressure on the oceans is now low and the winds, therefore, begin to move from land to sea. These are the north-east monsoons of the northern hemisphere.

The difference between the land and ocean pressures can be seen by noting the pressure for July and January, in the maps given on pages 71 and 72.

The south-west monsoon is much stronger than the north-east monsoon. It blows about 27 to 55 miles per hour. This is because the gradient in the case of the south-west monsoon is greater than in the case of the north-east monsoon. For example, the July pressure for Lahore is 747 mm. and for Colombo 756 mm. This gives a difference or gradient of 9 mm. The January pressure, on the other hand, is 764 for Lahore and 758 for Colombo which gives a gradient of 6 mm. only. In the accompanying maps the monsoon winds and the pressure over India and the adjacent lands have been shown. Note the difference in the pressure gradients as indicated by the spacing between the isobars.

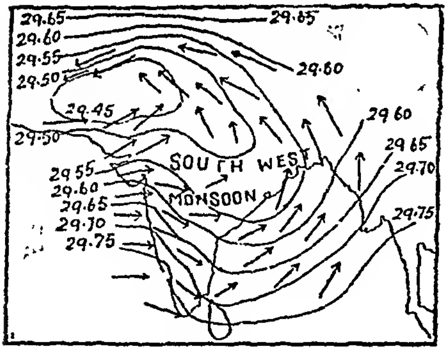

Fig. 36. Summer Monsoons.

The winter or the north-east monsoons are land winds and are, therefore, characteristically dry winds. The summer or the south west monsoons are ocean winds and, therefore, characteristically wet. The heavy rainfall of summer is an important feature of the

*Dr. Simpson, 'the South-West Monsoon' in the Quart. Journal of Royal Met. Society, London. Vol. 47, 1921.

south-west monsoon. This monsoon has always been associated

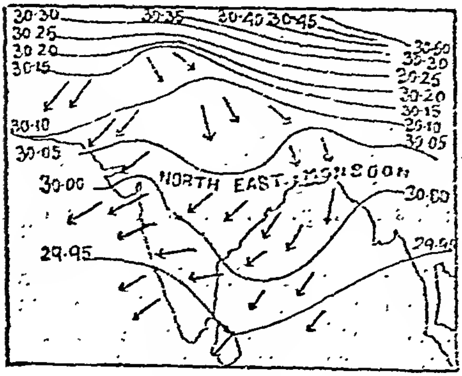


Fig. 37. Winter Monsoons.

with rain—indeed copious rain. The rain as dependent upon the monsoon is not the simple result of a single physical condition. It is produced by a combination of circumstances involving consideration of various factors, including the relation of mountain ranges.

Besides Asia, the other parts affected by monsoons:—East Africa, Australia and the United States of America. However, the monsoons are characteristic on the east coast of land masses in the northern hemisphere.

## Land and sea breezes

Another example of the terrestrial modification of the regular planetary winds is found in the Land and Sea breezes. These breezes

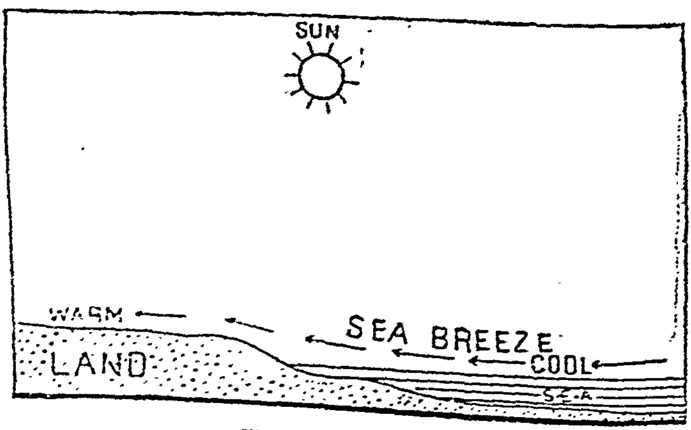


Fig. 38. Sea Breeze.

result from the daily inequality in the heating of land and water and the consequent reversal in the flow of air from the one to the other. During the day, land is heated more than water. Low pressure develops on land in comparison with the pressure on water. Air begins to flow from the high pressure on water towards the low pressure on land. This flow is called the *sea breezes* and generally blows on the coasts from about 10 A. M. to about sunset. Sea

breezes penetrate in some cases to about 20 to 30 miles into the interior of the land. Their effect is very much marked on the daily weather conditions in the tropics, where the land and sea breezes are more common than in the temperate regions. In some cases, they bring down the temperatures of the day by several degrees.

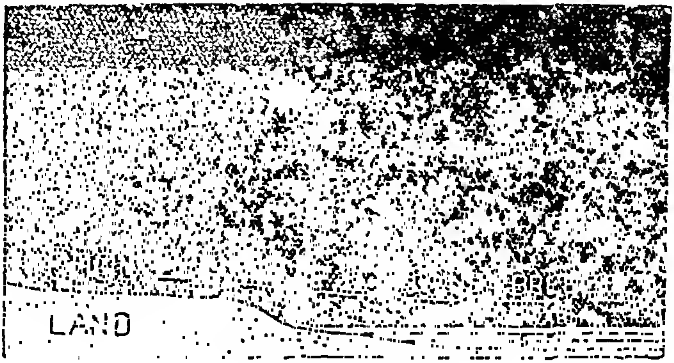


Fig. 39. Land Breeze.

During the night, land cools down more quickly than water. Water is, therefore, warmer than land. The higher pressure is now on land than on water. Air, therefore, begins to flow from land to water. This is known as *land breeze*. It blows commonly during the night on the coasts. Figs. 38 and 39 illustrate the principle of the land and sea breezes.

The land and sea breezes are very shallow, extending normally to a height of about 200 feet only*. These winds blow roughly at right angles to the isotherms. No satisfactory detailed theory of land and sea breezes seems to have been worked out by the meteorologists hitherto.

Mountain and valley breezes also belong to this class of terrestrially modified winds. During the day the air lying in the valley is heated and rises up. The evidence of the rising air is provided by the cumulus clouds which collect about the peaks of the mountains in the afternoon. During the night, the cold air which now lies on the slopes of the mountains begins to slip down into the valley. The rising air during the day is called the *valley breeze* and the sliding air from the mountain slopes during the night is called the *mountain breeze*.

Sometimes, during the winter in the places lying at the foot of a high plateau cold air slides down in large masses from the top of the plateau. This wind is called *Mistral* in France and *Bora* in

*Brunt ; Physical and Dynamical Meteorology, p. 381.

Dalmatia in Europe. When air descends on the leeward slopes of high mountains, it is warmed up. This descending air on the leeward slopes is called the *Foehn* wind in Europe and *Chinook* wind in America.

## Observation of Wind

The name given to a wind is that of the direction from which it blows. Thus, the north wind is the one that comes to us from the north. The velocity of wind is measured by an instrument called the *anemometer*.

THE BEAUFORT WIND SCALE.

| *Beau-fort No.* | *Wind* | *Arrow.* | *Speed. m.p.h.* | *Commonly observed effects of corresponding winds.* |
|---|---|---|---|---|
| 0 | Calm .. .. | ⊙ | 0 | Calm, smoke rises vertically. |
| 1 | Light air .. | | 2 | Direction of wind shown by smoke drift, but not by wind vanes. |
| 2 | Light breeze .. | | 5 | Wind felt on face; leaves rustle, ordinary vane moved by wind. |
| 3 | Gentle breeze .. | | 10 | Leaves and small twigs in constant motion; wind extends light flag. |
| 4 | Moderate breeze | | 15 | Raises dust and loose paper; small branches are moved. |
| 5 | Fresh breeze .. | | 21 | Small trees in leaf begin to sway, crested wavelets form on inland waters. |
| 6 | Strong breeze .. | | 27 | Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty. |
| 7 | Moderate gale .. | | 35 | Whole trees in motion; inconvenience felt when walking against wind. |
| 8 | Fresh gale. | | 42 | Breaks twigs off trees; generally impedes progress. |
| 9 | Strong gale .. | | 50 | Slight structural damage occurs (chimney pots and slates removed). |
| 10 | Whole gale .. | | 59 | Seldom experienced inland; trees uprooted; considerable structural damage occurs. |
| 11 | Storm .. .. | | 68 | Very rarely experienced; accompanied by widespread damage. |
| 12 | Hurricane .. | | above 75 | |

The velocity of wind varies with height above the ground as the obstruction on the ground tends to reduce the speed of the wind. The wind at 100 feet is a good deal stronger than the wind at 20 or 30 feet above the ground. In order to get comparable speeds from all stations, a common height of 33 feet above ground is used in all observations of the wind. There are special signs used on weather maps to indicate the wind velocities. These signs have been fixed for international use and are called the Beaufort Wind Scale. The scale is to be found above.

## CHAPTER VI

# ATMOSPHERE—*(continued)*

ATMOSPHERIC MOISTURE—ABSOLUTE HUMIDITY—RELATIVE HUMIDITY—CAUSES OF CONDENSATION—HYGROSCOPIC SUBSTANCES—TYPES OF CLOUDS—GEOGRAPHICAL DISTRIBUTION OF CLOUDINESS—RAINFALL—DISTRIBUTION OF RAINFALL—SNOWFALL—ROTATION AND RAINFALL.

### Atmospheric Moisture

Water vapour is an important constituent of the atmosphere. The various forms produced by water vapour ; cloud, fog, rain and snow provide us with the most *visual* evidence of the presence of atmosphere on the earth. There is hardly any other weather element whose absence causes so much inconvenience to the organic life on the earth as of rainfall. We have already seen how the presence of water vapour in the atmosphere affects the temperature on the earth's surface. Yet, with all its importance, we find that water vapour is only a minor constituent of the atmosphere. The table on page 57 shows the percentage of the water vapour in the atmosphere at different elevations. Practically, half of all the water vapour present in the air lies within the first 6,000 feet of elevation.

Atmosphere picks up moisture from different sources on the earth's surface. Heat applied to moisture evaporates it, *i.e.*, converts it into vapour. This water vapour mingles with the atmosphere and becomes a part of it. The largest source of moisture to the atmosphere is the ocean. The ocean covers about three-fourths of the earth's surface and can, therefore, supply enormous quantities of moisture to the atmosphere, only if it could carry it ! The vegetation cover on land and the minor water bodies on the continents also yield a considerable supply of moisture to the air.

Water vapour is, however, a bulky thing for the atmosphere to carry or to absorb within itself. That is why water vapour forms only a small proportion of the total volume of atmosphere, even in its lowest parts near the earth's surface where the supplies of moisture available are large. Moisture can remain in the air only so long as it is in the form of *vapour*. The moment it ceases to be vapour, because of condensation, it must leave the atmosphere. The thing which helps the atmosphere to contain moisture within it is, therefore, heat. It is through heat that water is evaporated or converted into vapour, and it is the loss of this heat that compels atmosphere to give up moisture. In other words, *warmer the air, larger the amount of water vapour that it can carry.*

The presence of water vapour in the air is described as its *humidity*. The actual amount of moisture present in the atmosphere at any time is called its *absolute humidity*. The absolute humidity is expressed in grains per cubic foot of air.* When the air has all the moisture that it can hold at its present temperature, it is said to be *saturated*. A saturated air cannot hold any more moisture unless its temperature is raised. The proportion that the actual amount of moisture present in the air, *i.e.*, its absolute humidity bears to the total amount of moisture which can be held by the air at that particular temperature is called the *relative humidity* of that air. Relative humidity of air is always expressed as a percentage. Suppose, for example, that the temperature of air at a place is 70°F. and its absolute humidity is 4 grains. Now we find from a table calculated from previous observations, that the total amount of moisture which an air at 70°F. temperature can hold is 8 grains. Therefore, it can still hold 4 grains more. Or its relative humidity is 50 per cent. Relative humidity of the air at any place can be changed only by changing the amount of moisture in it or by changing its temperature.

The following table gives the moisture holding capacity of one cubic foot of air at different temperatures.

| Temp. F.° | Vapour. Grains | Increase over preceding temperature. Grains |
|---|---|---|
| 30° | 1·9 | ... |
| 40° | 2·9 | 1·0 |
| 50° | 4·1 | 1·2 |
| 60° | 5·7 | 1·6 |
| 70° | 8·0 | 2·3 |
| 80° | 10·9 | 2·9 |
| 90° | 14·7 | 3·8 |
| 100° | 19·7 | 5·0 |

It is clear from this table that the moisture-holding capacity of the air increases with the increase in temperature. What is important to note, however, is that this capacity grows with *increasing* rate. If you raise by 10° the temperature of the air from 60° F., to 70° F., you raise its capacity by 2·3 grains, *i.e.*, it can now hold 8 grains instead of 5·7 grains that it could hold when its temperature was 60° F. But if you raise by 10° temperature of the air from 90° F. to

*Absolute humidity is, however, most commonly expressed as equivalent of vapour pressure. That is to say, that portion of the total pressure of the volume of air which is due to the presence of water vapour. This is found out by means of an instrument called 'the Psychrometer.'

100° F., you increase its capacity by 5 grains, which is much more than 2·3 grains which was the increase in the first case. It is clear, therefore, that the air on a hot summer day or in the tropics can hold much more moisture than air on a cold winter day or in the higher latitudes.

Generally speaking, absolute humidity diminishes from the equator towards the poles. At the equator it is about 20 mm. while at the poles it is often less than 1 mm.

Relative humidity is the greatest on the oceans where it is 80 per cent or ·0, and the least on the continents, where it is about 50 per cent. The deserts, like the Sahara, have a very low relative humidity, only about 10 per cent. It should, however, be noted that the *absolute* humidity on some of the deserts may be very high. In the Sahara, for instance, the absolute humidity is about 10 mm., but owing to the high temperatures this gives only a low *relative* humidity.

Absolute humidity is an important factor in the amount of precipitation which may be received at any place. Where there is little moisture in the air, the precipitation will be small unless larger quantities are imported by an incoming air.

Relative humidity may determine whether or not there can be precipitation. It also determines the amount and rate of evaporation that can take place.

The moisture in the air is constantly changing as the atmosphere is never steady, owing to the changes of temperature and pressure. Evaporation and condensation are the two phenomena that are always related to the water vapour in the air. Evaporation adds water vapour to the air, condensation releases water vapour from the air. The first results from the *gain of heat*, while the second results from *loss of heat*.

There are two principal ways in which the atmosphere loses its heat as a result of which condensation results. These are:—

(*a*) Contact with a cold surface; *e. g.*, cold surface of the earth, cold water or cold layer of air. If this contact brings about a sufficient lowering of the temperature of the air, condensation takes place. The mass of air that can be cooled in this way is limited, however. The resultant condensation can release only small amounts of moisture in this way. Dew, white frost or fog are the forms that this condensation produces. None of these forms can give back to the earth's surface large quantities of moisture. This type of condensation is comparatively a surface phenomenon only.

(*b*) Expansion of rising air. Expanding air cools adiabatically at a rapid rate. It has been stated above that the adiabatic rate of cooling is about 5½°F. for every 1,000 feet of ascent. This cooling

affects considerable masses of air and condensation is, therefore, on a large scale. The condensation in this case takes the form of clouds. The clouds form at considerable elevations above the earth's surface. It is from these clouds that rainfall results.

Condensation cannot take place in the atmosphere without a nucleus or a central core on which the water could be deposited. The casual grouping together of a number of molecnles of water vapour cannot form drops of water either large enough or quick enough for the process of condensation to go on A substance is needed which has the quality of inducing condensation as soon as the temperature has fallen below the dew point*. Such a substance is called the *hygroscopic* substance. There are present in the atmosphere small particles of hygroscopic substances, numbering from about 2,000 to 50,000 per cubic centimetre of air. It is on these nuclei that condensation starts and clouds result.

If the nuclei are sufficiently hygroscopic, they may begin to absorb moisture from the atmosphere even before it is saturated. It has been frequently observed that in fogs the air is well below saturation. It must not be supposed that non-gaseous things in the atmosphere can act as nuclei.

It is also believed that atmospheric electricity by ionising the air helps the condensation.

Condensation upon ions can, however, take place when the dynamical cooling of the air passes a long way beyond the ordinary saturation point and there are few nuclei present.

Condensation by mixing of two masses of moist air at different temperatures is also a common feature. The capacity of the air for moisture increases faster than its temperature, as stated before, and hence two masses of air at different temperatures neither of which is actually saturated, gives a mixture at mean temperature that is more than saturated.

## Clouds

The clouds are formed of minute particles of water. These particles are held by the rising air and cannot fall down unless they are large enough. In many cases, the falling drops of water are re-evaporated during their fall, before reaching the ground.

If condensation takes place when the temperature has gone down to 32°F., the resultant moisture freezes into snow or ice crystals. Clouds at very high elevations, therefore, consist of small particles of snow and ice.

*The temperature at which an air is saturated is said to be its dew point.

There are four principal types of clouds, as distinguished by Howard. They are :—

(1) Cirrus, (2) Stratus, (3) Cumulus, and (4) Nimbus.

(1) Cirrus clouds are the highest clouds, round generally from 8,000 to 12,000 metres. Owing to their great altitude, they are made up of minute crystals of ice. They are generally white and

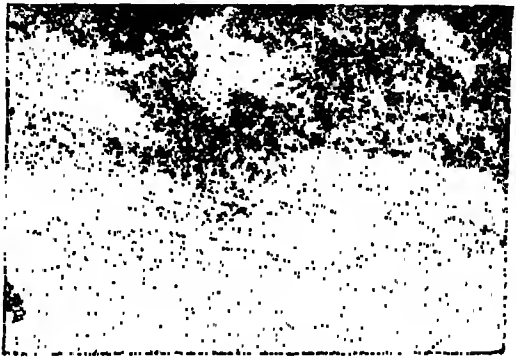

Fig. 40. Cirrus Clouds.

give no shadows. They assume various shapes. Sometimes, they are like curls of hair; at others, they are like an unbroken thin veil of fibrous texture over the whole sky. Often they seem to be converging on the horizon. They sometimes produce halos around the moon and the sun.

(2) Stratus clouds cover the sky like a grey sheet unbroken from horizon to horizon. There are no changes in the shape of this cloud.

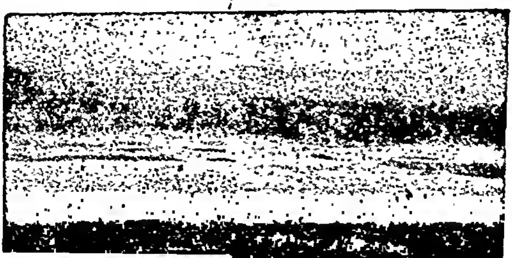

Fig. 41. Stratus Clouds.

(3) Cumulus clouds are distinguished by their flat base and a cauliflower-like top. Blue patches of sky separate one cumulus from

the other. The cumulus clouds are formed at the tops of convectional air currents that rise on a hot and moist day. They, sometimes, develop into thunder clouds. Their average height is about one mile above the ground though their top may extend to about three miles.

Fig. 42. Cumulus Clouds.

(4) Nimbus clouds are the thick, dark masses of cloud from which rain is being received or it has just stopped. These clouds are very low, sometimes almost touching the ground.

Often one or more types of clouds are found mixed together. They are then given the combined name of the various types forming them, *e.g.*, strato-cumulus or cumulo-nimbus.

There are ten such combinations that are recognised by an international agreement among the meteorologists, and are in use.

Fog is also a kind of cloud which occurs on the ground level. Fog at a great elevation is cloud. Chilling of the air resulting either from a contact with a cold body, or from excessive radiation on a cold and clear night produces fog. There are two types of fog:—(*a*) advection fog, and (*b*) radiation fog. When chilling results from contact with a cold body, the fog produced is called the *advection fog*. When fog is produced owing to radiation, it is called *radiation fog*. The fogs along the sea coast are of the former type, while the fogs occurring on a winter night in the interior of the land area of the latter type.

## Cloudiness

The general distribution of cloudiness of the skies has a tendency to be parallel to the latitudes. The maximum of cloudiness is found at the equator, and this maximum generally follows the highest sun towards north or south of the equator.

The minimum of cloudiness is found towards the lines of the Tropic, between 15° and 35°, north or south latitudes. Another region of great cloudiness lies between 55° and 60° N. and S. In the higher latitudes, the cloudiness diminishes near the Poles.

This generalised distribution of cloudiness is modified considerably, as will be noted from the following cases :—

(1) It is found that the continents have greater cloudiness than oceans.

(2) Cloudiness is more common with the centres of low pressure (cyclones) than with centres of high pressure (anti-cyclones).

(3) The windward slopes of mountains are more cloudy than the leeward slopes. An example of this is furnished by Norway which, being on the windward side, has greater cloudiness than Sweden which is on the leeward side.

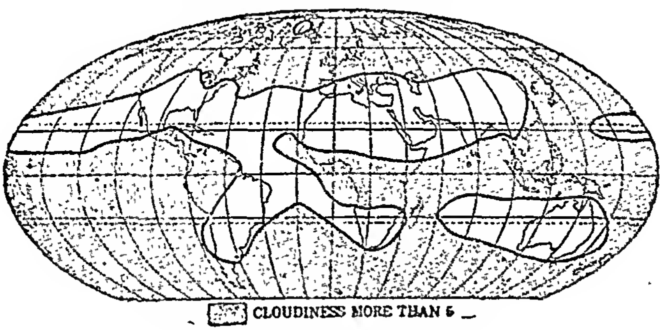


Fig. 43. Mean Annual Cloudiness.*

## Rainfall

Rainfall results from clouds. When condensation has gone on for a sufficiently long time, or when the cloud has been pushed up sufficiently high to enable the formation of big drops of water, the drops fall from the clouds as rain. The essential requirement of rainfall is, therefore, the expansion of a *rising air* mass. Anything that causes the air to rise will ultimately bring about rainfall. This rise is generally due to three factors and, therefore, rainfall is said to be of three types. These types are :—

(*a*) Convectional rainfall,

(*b*) Orographical or Relief rainfall, and

(*c*) Cyclonic rainfall.

*Cloudiness is always expressed in tenths of the sky. In this map 5 means that 5/10 or half the sky is clouded.

(*a*) When the air is heated it rises and expands. The subsequent result of this heating is that convectional currents of air are formed. On tops of these currents, condensation begins to take place and clouds form. Sometimes, condensation is also brought about by the mixing of two air masses at different temperatures. Convectional currents give rise to cumulus clouds which often develop into thunderstorms and cause rainfall. This type of rainfall is associated with summer months and the hotter parts of the day. In the continental interiors, when they are considerably heated, thunderstorms due to rapidly rising convectional currents form and rainfall results. The convectional rainfall is received by heavy downpours and is shortlived, for the cloud covers only a small part of the sky and quickly moves to another part.

(*b*) Orographical or Relief rainfall is due to the air being forced to rise against a high mountain. This rise results in expansion and cooling of the air which produces clouds and rain. It is generally from the prevailing winds that such rainfall occurs. The windward slopes of mountains alone get. rain, the leeward slope being dry. The rainfall that takes place at the foot of the Himalayas in India is of this type. It is noticed how the Tibetan plateau on the leeward side of these mountains is entirely without rain. The rainfall that is received at Cherrapunji in Assam is also of orographical type. The moisture-bearing winds from the sea strike against the Khasi hills, which they try to ascend, and cause one of the heaviest rainfalls of the world. There are examples of this type of rainfall all over the world. This type of rainfall can occur at any time of the year. But in summer when the air is warm and, therefore, its moisture content great, the rainfall is generally heavier than at other times.

(*c*) Cyclonic rainfall is associated with the passage of a 'Low'. Air is forced up as it is converging and clouds and rainfall, therefore, result In the cyclone some of the air is drawn from a warmer region and is, therefore, capable of giving considerable amount of rain on being condensed. This warm air is forced to ascend a mass of cold air both at the front of the Low Pressure centre and at its back. This mixing of warm and cold air is naturally conducive to rainfall. The rainfall of this type comes down in gentle showers and is not heavy. The winter rainfall in Northern India is of this type. The rainfall associated with a cyclone comes during two distinct periods in the passage of a cyclone. The first showers are received when the front of the cyclone is passing and the second when its tail is passing us. Between these showers, the weather is dry.

## Surface Distribution of Rainfall

The convectional rainfall, which is most common in the equatorial regions, is marked by a seasonal variation. The maximum is at

the time of the highest sun and the minimum at the time of the lowest sun. In the equatorial regions there are two rainy seasons and two dry seasons following the two passages of the sun, once from the equator towards the tropic line and then back from the tropic line towards the equator. The two rainy seasons come nearer and nearer to each other as one approaches the tropic line, until at the tropic line itself there is only one rainy season separated by one long dry season. The following diagram shows the rainfall regime in the equatorial regions :—

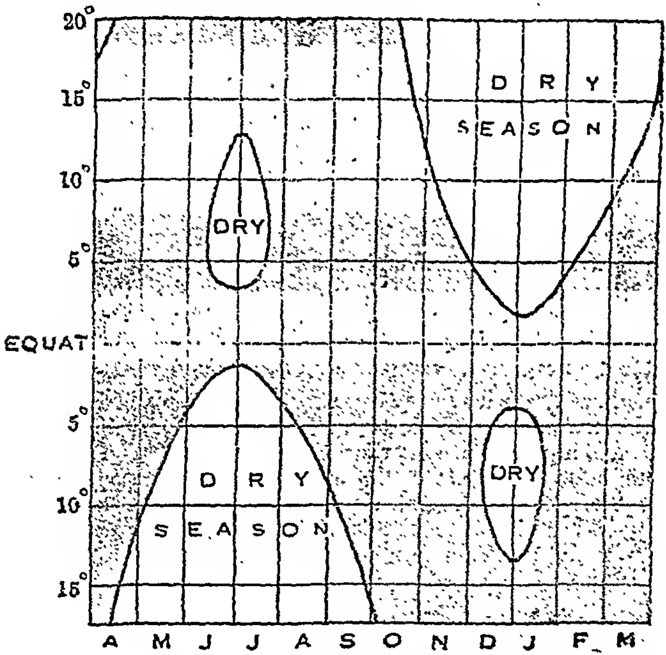


Fig. 44. Rainfall in the Equatorial Regions.

It is seen from the above diagram that there is no dry season at the equator and, for some distance, north and south of it. Further north or south, there are two dry seasons, one long and one short. Towards the Tropic of Cancer or the Tropic of Capricorn the shorter dry season disappears, and there is only one long dry season coinciding with the winter season and one rainy season coinciding with the summer. The long dry season comes very near the equator for a short time when the sun is far away shining overhead in the other hemisphere. For example, during the months of December and

January when the sun is overhead near the Tropic of Capricorn in the southern hemisphere, the dry season in the northern hemisphere approaches to within 2° of the equator. From about 4° to 14° on both sides of the equator there appears a second dry season which lasts only for about two months, June and July in the northern hemisphere and December and January in the southern hemisphere. It is to be noticed that when there is this short dry season in one hemisphere, there is the long dry season in the other hemisphere. Note that the long and the short dry seasons in the opposite hemisphere are opposite to each other. In short, the seasonal variation of rain in the tropics is related to the change in the path of the sun.

Outside the tropics, convectional rainfall is very rare. The rainfall is either relief rain or cyclonic rain. The seasonal variation of rainfall outside the tropics is due to the change in the prevailing winds. When the prevailing winds are from the ocean, rainfall is received; when on the other hand, the winds are from land, there is a dry season. This is very clearly marked in the case of India and other monsoon lands.

In the temperate regions the rainfall is associated with the passage of the cyclones, which are more frequent during winter than during summer. In the temperate regions, rainfall is, therefore, heavier in winter than in summer. Summers are not, however, entirely dry. Thunderstorms are common during this season, and considerable rainfall is received from them.

Just as there is a seasonal variation of rainfall depending upon the passage of the sun or the change in the prevailing winds there is also a Daily or Diurnal variation of rainfall. The diurnal variation is more marked in the tropical and equatorial regions than elsewhere. In these regions, more rain falls in the afternoons than during other times of the day. This is related to the highest temperatures at that time of the day. The afternoon maximum of rainfall is common with the convectional type of rainfall everywhere.

On the oceans, the rainfall variation and temperature variation are reversed. More rain falls on the oceans during the night than during the day. In the temperate regions, more rain falls during the mornings than during other parts of the day.

The map on page 97 gives the seasonal distribution of rainfall.

The surface distribution of rainfall varies considerably. The rainiest part of the earth are found in the tropical and equatorial region. This is specially true of those places in these regions which are situated on the windward slopes of the mountains. The two wettest places on the earth are Cherrapunji in Assam with an annual rainfall of 424 inches and Mt. Walaleale, on the island of Kanai in the Hawaiian Islands, with an annual rainfall of 476 inches. Note

from the map given on page 97 that most of the rainiest areas fall within the Tropic of Cancer and the Tropic of Capricorn. The areas within this belt which have little rain are mainly under the

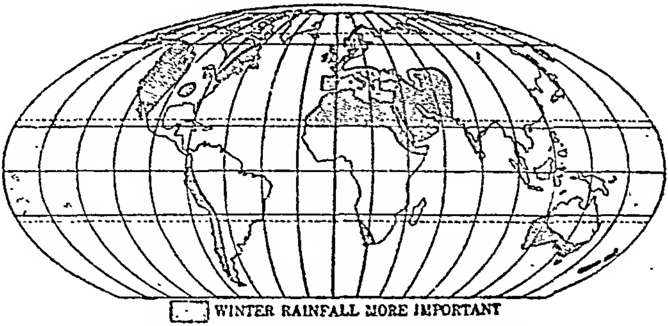


Fig. 45. Seasonal Distribution of Rainfall.

influence of trade winds, which are ordinarily dry winds; or cool ocean currents are present along their coasts. It is between 20° and 35° latitudes that the rainfall decreases rapidly. In this belt are found the important deserts of the world. These deserts are characteristic of the western margins of land masses in these latitudes.

Water vapour which is condensed as rain is supplied to the air through evaporation. There is, therefore, a close relationship between rainfall and evaporation. The excessive rainfall that occurs in the equatorial regions is really due to the enormous amount of evaporation that goes on in these regions. The following table taken from Brueckner* shows the distribution of rainfall and evaporation in different latitudes:—

*Distribution of Rainfall and Evaporation*

| Latitude | On Oceans | | On Land | | World | |
|---|---|---|---|---|---|---|
| | Rain | Evaporation | Rain | Evaporation | Rain | Evaporation |
| N. | | | | | | |
| 90—80 | 0·5 | 0·2 | 0·1 | 0 | 0·6 | 0·2 |
| 80—70 | 0·4 | 0·7 | 0·9 | 0·3 | 3·3 | 1·0 |
| 70—60 | 0·7 | 0·7 | 4·7 | 1·6 | 7·3 | 2·3 |
| 60—50 | 10·4 | 4·4 | 7·4 | 5·3 | 17·8 | 9·7 |
| 50—40 | 17·6 | 10·5 | 8·4 | 5·5 | 26·0 | 15·9 |
| 40—30 | 10·7 | 20·0 | 8·1 | 5·9 | 18·8 | 25·9 |

*E. Brueckner in Geographische Zeitschrift, 1905.

| Latitude | On Oceans | | On Land | | World | |
|---|---|---|---|---|---|---|
| | Rain | Evaporation | Rain | Evaporation | Rain | Evaporation |
| N. | | | | | | |
| 30—20 | 5·5 | 28·9 | 11·9 | 7·6 | 17·4 | 36·4 |
| 20—10 | 19·7 | 37·8 | 10·7 | 8·9 | 30·5 | 46·6 |
| 10—0 | 47·5 | 34·0 | 17·4 | 11·6 | 64·9 | 45·6 |
| S. | | | | | | |
| 0—10 | 32·2 | 38·4 | 18·8 | 12·7 | 51·0 | 51·2 |
| 10—20 | 22·2 | 40·1 | 10·3 | 8·5 | 32·5 | 48·5 |
| 20—30 | 15·9 | 34·6 | 6·0 | 3·8 | 21·9 | 38·4 |
| 30—40 | 28·6 | 28·8 | 2·3 | 2·1 | 30·9 | 30·8 |
| 40—50 | 28·0 | 17·7 | 0·9 | 0·5 | 28·9 | 18·2 |
| 50—60 | 17·7 | 5·8 | 0·2 | 0 | 17·9 | 5·9 |
| 60—70 | 5·0 | 1·5 | 0·2 | 0·1 | 5·2 | 1·6 |
| 70—80 | 0·5 | 0·2 | 2·6 | 0·4 | 3·1 | 0·6 |
| 80—90 | 0 | 0 | 1·2 | 0·2 | 1·2 | 0·2 |
| | 267·1 | 304·2 | 112·1 | 75·0 | 379·2 | 379·2 |

Beyond 35° latitude, the westerlies predominate, and the rainfall is heavier on the western margins of land masses than on their eastern margins. The effect of relief is marked on the distribution of rain in these regions. The westerlies do not penetrate far into the interior of the land during winter, because the lands are then covered by high pressure anti-cyclones. Their effect on rainfall distribution is more marked during summer when they penetrate into the interior of the lands. The places nearer the sea, however, receive more rain than places far into the interior; the moisture contained in the westerlies is lost considerably in their passage into the interiors.

In the polar regions, the rainfall is very little. For, owing to the cold temperatures, the quantity of water vapour in the air is limited here.

The map on page 97 gives the distribution of rainfall during the year.

## Snowfall

When condensation takes place at 32°F. or below, it is in the form of snow. In the higher latitudes and higher altitudes where, owing to the cold temperatures, the amount of moisture held in the air is not considerable, the saturation point of the air reaches when the temperature has considerably fallen. At the top of the high mountains and in the continental interiors in the higher latitudes, the pre-

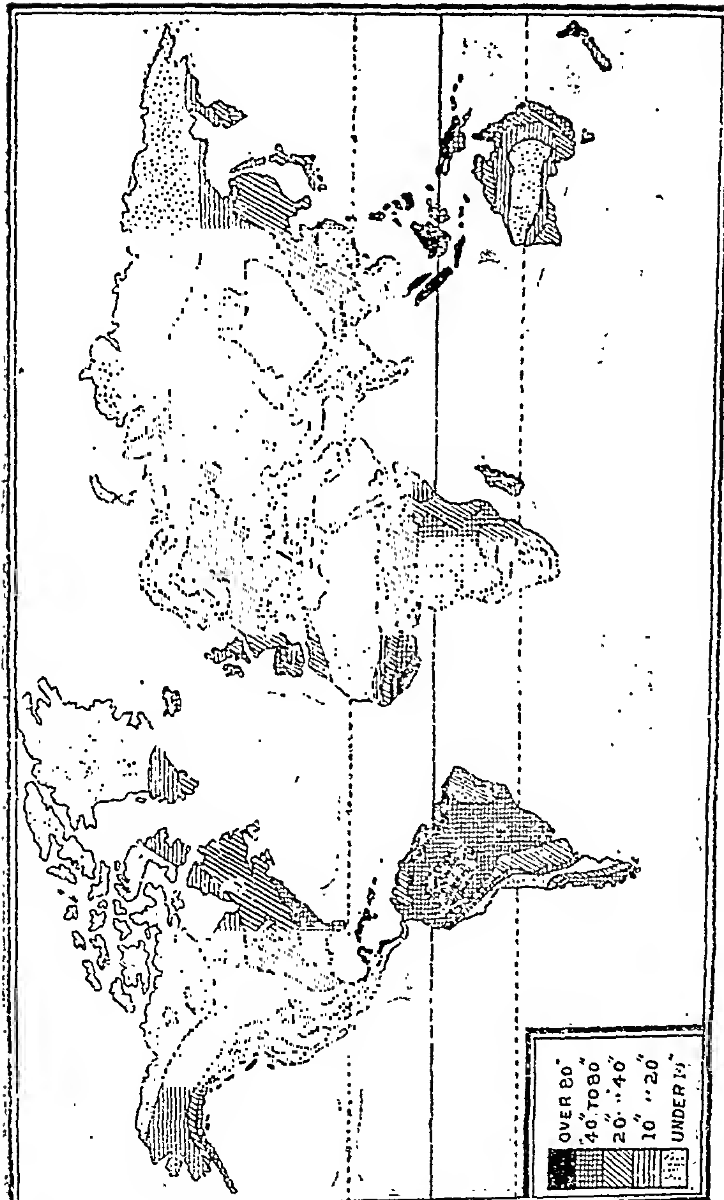


Fig. 46. Distribution of Mean Annual Rainfall.

cipitation during winter comes mostly in the form of snow. The isotherm of 32°F. in January passes through most of Europe, northern Asia, and Canada. In these areas, therefore, there is considerable snowfall during winter. The amount and the frequency of snowfall is greater in the continental interiors than near the coasts.

## Rotation and Rainfall

The distance from the sea has little effect on the amount of precipitation in the tropical parts of land masses, because most of the rain here is convectional on which the influence of the prevailing winds is not considerable. In North America and Eurasia, however, outside the tropics, this distance is of great importance in the distribution of rainfall.

Apart from the convectional type of rainfall in the tropics, there is also the fact that near the equator a difference in temperatures between the air on land and the air on the adjacent sea gives rise to a compensating circulation in which maritime air may move without hindrance, except where relief features prevent it, directly into the heart of the land, because the deflection due to the earth's rotation is the least near the equator. Outside the tropics, a contrast in temperature between land and the surrounding sea gives use to a circulation about the land, that is in general terms *cyclonic* if the land is warmer than the sea, and *anti-cyclonic* if the land is cooler. The earth's rotation is an obstacle to the free passage of the maritime air into the interiors of the lands remote from the sea. The winds that would penetrate without delay into the interiors of large land masses in the tropics, enter into continents in higher latitudes only intermittently and with decreasing frequency farther island, owing to the deflection caused by the earth's rotation.

Here, the gravitational flow of air from the sea towards land is deflected to the right and becomes, therefore, at first a movement parallel to the coast and then, if the pressure gradient from the sea to land is not enough to prevent further deflection, continues as a return movement to the sea. Air movement from the sea to the land along the pressure gradient is checked by the earth's rotation, so that there is little opportunity for air on the cool side of the system to escape to the warm side. On the other hand, as long as the pressure gradient is becoming steeper, and hence the circulation more intense, air is constantly being thrust by deflection from the warm to the cool side of the circulatory system. This causes the transfer of air from land to sea which lowers pressure on land and raises it on sea, and so builds up a pressure gradient. It is, thus, only through a cyclonic circulation that the rain-bearing winds can give rainfall into the interiors of land masses in higher latitudes.

CHAPTER VII

# ATMOSPHERE—(*continued*)

DISTURBANCES—TROPICAL CYCLONES—BAY OF BENGAL CYCLONES—ARABIAN SEA STORMS—TROPICAL AND TEMPERATE CYCLON S CONTRASTED—MIDDLE LATITUDE CYCLONES—POLAR FRONT THEORY—WEATHER IN A CYCLONE—ANTI-CYCLONE.

## Atmospheric Disturbances

The general circulation of the atmosphere that we have studied in a previous chapter gives us an idea of only the mean conditions of the atmospheric circulation. The conditions from day to day vary considerably. These day-to-day variations are concerned mostly with the redistribution of the mass of air that is displaced from one part of the earth to the other. For, there is no factor in the atmosphere which is capable of heaping up air in one region at the expense of the other. The idea of the *continuity of the air mass* is also supported by the fact that there is a substantial constancy of the atmospheric pressure on the earth's surface. The atmospheric pressure at sea level is about 1,000 mb., and the limits within which this pressure varies at sea level is not more than 30 mb. of the mean value, *i. e.*, the variation is not more than 3 per cent.

The study of the pressure distribution on the earth's surface revealed that there are some belts of exceptional pressure conditions. These are :—(*a*) the low pressure belts called the doldrums, and (*b*) the high pressure belts called the sub-tropical highs or the 'Horse Latitudes'. There are also the sub-polar lows and the polar highs, but we know very little about these belts yet. The origin of these belts, as we saw in chapter V above, is thermal or dynamic. But the result is that air is being drained away from the equatorial regions, and is being piled up in the sub-tropical regions. This state of affairs must be corrected in order to maintain the continuity of the air mass, and to maintain the general circulation. The necessary correction is brought about through the agency of the atmospheric disturbances in the general flow of the atmosphere. According to Exner*, the cyclones and anti-cyclones are dynamically necessary for the maintenance of the general circulation.

It has been noted above that the belt of sub-tropical highs is invaded by cyclones and anti-cyclones. At the back of the cyclones and at the front of the anti-cyclones, air currents move equatorward which compensate the mass of air taken away from the equator, and

*Exner : *Dynamische Meteorologie*, p. 216, 2nd Edition.

in this way a vast accumulation of the air in the higher latitudes is avoided. The importance of the cyclones and the anti-cyclones, as redistributors of the air mass between the polar and the equatorial regions must, therefore, be realised. Cyclones, anti-cyclones and the areas in which they are active must, however, be regarded as parts of one general circulation of air currents.

The tropics and the temperate regions are the two important areas where the atmospheric disturbances are most active. There are various names given to those disturbances which are common in the tropics. Tropical cyclone, typhoon, tornado and hurricane are some of the names given to the tropical disturbances. For the temperate region disturbances the names of cyclones and anti-cyclones have been given.

## Tropical Cyclones

Unfortunately, the tropical cyclones have not been fully studied and there is, therefore, a considerable divergence of opinion among the meteorologists about them. Some people think that these storms originate at the rather diffuse boundary between two air masses widely different origin, one being of oceanic origin and the other generally of continental origin. They originate only over the oceans, specially along the poleward margins of the doldrums and are most numerous during the time when the doldrum belt is at its greatest distance from the equator. Here the trade winds are dying out and merging with the doldrums.

In all the cyclones, the isobars are of a circular shape enclosing an area of low pressure. The tropical cyclones encloses only a very small area. Generally the diameter of this cyclone is never more than 200 miles, though in some cases a diameter of only about 32 miles has been noted The pressure at the centre is very low, generally about 960 mb. In some cases as low a pressure as 933 mb. has been observed. The barometric gradients are extremely sharp, so that the wind blows with a terrific speed, sometimes more than 200 miles per hour. The winds blow anti clockwise round the centre. The wind velocity increases in intensity from the outer limit to the centre. The centre, however, consists of a calm where there is no wind. The life history of tropical cyclones is composed of the formature stage, the stage of immaturity, the stage of maturity and the stage of decay. According to their intensity tropical cyclones are classified by the U. S. Weather Bureau into Tropical disturbance, Tropical depression, Tropical storm and Hurricane.

The approach of the tropical cyclone is indicated by the appearance of cirrus clouds in the sky. These clouds are emerging from the place which is occupied by the centre or the 'eye' of the cyclone. They are quickly succeeded by other cloud-forms of which the last are the nimbus. The nimbus clouds preceding the tropical

cyclone are very thick and blot out the sun entirely. A heavy downpour of rain generally follows. Rainfall is heaviest in the right front quadrant, in the Northern Hemisphere. At the tail end of the cyclone, rain is followed by sleet, and the weather is clear again. The approach of the tail end is heralded by thunder and other electrical discharges. The approach of the tropical cyclone is generally preceded by an oppressive, calm atmosphere.

Andrew Brown of the U. S. Navy describes the "Eye" of a hurricane as follows :—

"Suddenly the plane rushed into nearly still air. The black and stormy weather dropped behind, cut off sharp as a wall !!! Clouds were high, thin, and whitish. The orange sun was a baleful, sickly orb...........The quiet 'eye' was only about 20 miles in diameter."

The modern explanation of hurricanes is given below :—

In the sultry doldrums, humidity is high, heat intense, and evaporation enormous. No one yet understands just how this combination starts the storm. The birth of the hurricane begins with moist air, heated by the sun, and rising from the surface of the tropical sea.

When the rising air produces rain, it also feeds back fabulous amounts of latent heat to the air. This heat is one main source of hurricane's power. According to Dr. W. J. Humphreys a full-fledged hurricane generates more energy than a thousand atom bombs exploding simultaneously.

As the air goes spiralling upward, more hot and moist air rushes inward from all sides to replace it and keep the updraft moving. Whirling faster and faster due to the earth's rotation this spiral becomes a hurricane when its winds reach a speed of 75 miles per hour. Drawing ever tighter about the centre, the winds form a roaring ring about a central area of calm air, the eye, 15 to 30 miles across.

A hurricane generally covers 200 to 300 miles across, but only 7 to 8 miles in vertical depth. The storm as a whole moves at a speed of about 10 to 20 miles per hour.

Born at sea, the hurricane also dies at sea, which may be about 10 days after its birth and about 3000 miles away from the birth-place. Most of the hurricane belt is the 'empty ocean'.

The right half of the hurricane as one looks forward along its path of movement is the more violent. This is because in that section the forward speed of the whole storm is added to its winds. On the left the winds are slower.

Owing to the damage associated with the hurricanes, they are tracked with aeroplanes. A Hurricane Warning Centre at Miami in U.S.A. was set up in 1943.

The effects of the tropical cyclones are most serious. Not only do they cause damage to property and life on account of the violence of the winds associated with them, but they also give rise to huge waves on the sea which sometimes leave behind nothing but destruction on the coasts they visit. It was a huge sea wave like this that caused the death of at least 100,000 persons in Bengal when it visited the estuary of the Ganges on 31st October, 1876.

On September 21, 1938 a hurricane in U.S.A. picked 4 million bushels of apples in twenty-four hours. It ripped through New England forests like a big electric razor chipping off trees.

The path followed by the tropical cyclones is often irregular. But, very generally, it can be said that the path followed by the tropical cyclone is a parabola whose axis is parallel to the equator and whose concave side is turned towards the east. The following map gives the general paths of the tropical cyclones :—

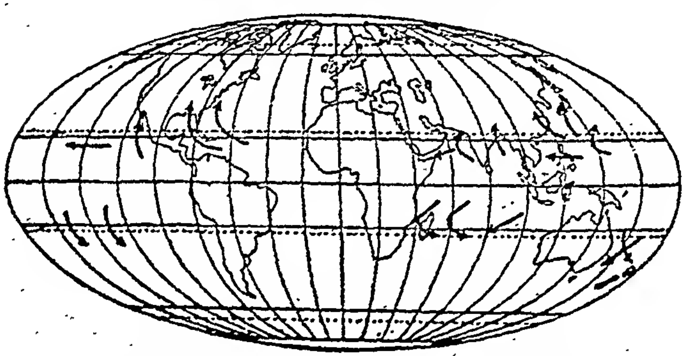

Fig. 47. Most Frequented Paths of Tropical Cyclones.

The map shows that the path of the tropical cyclone has the following characteristics :—

(1) Between the equator and 15° latitude the path turns towards the west ;

(2) Between 15° and 30° latitudes the path is very uncertain, but tends towards the north in the northern hemisphere and south in the southern hemisphere ;

(3) Beyond 30° the path turns towards the east.

The progress of the tropical cyclone is slow in its westward march ; only 5 to 15 miles per hour. This is true also of the northern or southern course. But in its last stage the progress is rapid, making about 30 miles per hour. The cyclone generally attains greater speeds in the southern than in the northern hemisphere. Cases have been observed, however, where a cyclone had been quite stationary.

The tropical cyclones occur mostly at the end of summer when the doldrums are farthest away from the equator. Visher[1] gives the following table of the frequency of tropical cyclones :—

**Annual frequency of tropical cyclones**

| Region of Occurrence | Number of storms |
|---|---|
| Western North Pacific | 30 |
| South Indian Ocean | 13 |
| Australia and Coastal Seas | 13 |
| Bay of Bengal | 8 |
| West Indian Seas | 5 |
| Arabian Sea | 4 |

## Bay of Bengal Cyclones

According to Dr. Ramanathan[2] there are three periods of tropical cyclones :—(1) the pre-monsoon period (April—June), (2) the monsoon period (July—September), and (3) the post-monsoon period (October—December). Of these the pre-monsoon and the post-monsoon cyclones are the most numerous and the most severe. These storms start in the Bay of Bengal or in the Pacific and enter the Bay by way of the Gulf of Siam. The origin of these storms is due, according to Dr. Ramanathan, to a formation of an active front at the meeting place of the southerly equatorial air and the northern air, which is a preliminary to the formation of the depression in both the pre-monsoon and the post-monsoon types.

In the pre-monsoon cyclone the forepart of the advancing column of fresh southerly air is called the 'monsoon front' or the 'moist cold front', because it is associated with a fall of temperature and an increase of relative humidity. The warm dry air from the hot land at the north forms a 'warm dry front' and ascends over the monsoon air when the two fronts meet. At an altitude of 3 to 4 km. the monsoon air is warmer than the land air, so it spreads out into the region of land air. The pre-monsoon storms have strong winds and squalls occurring in advance of the warm dry front and generally in the monsoon sector.

In the post-monsoon storms there is an incursion of warm, humid air from the equatorial seas which meets the cold land air of the north-west. This ascends over the cold land air, leading to the formation of a 'warm front.'

1 Visher ; *Royal Geographical Journal*, Vol. XVII, 1921.
2 Dr. K. R. Ramanathan ; Sc. notes, Indian Met. Dept., Vol. 3, No. 18, 1931.

The monsoon cyclones are about the same in origin, and structure. They are disturbances on the *quasi*-stationary front between the monsoon air in the Gangetic Plain and the dry north-west air.

According to our present experience, the northern half of the Bay is always quite free from storms from the end of the first week in December to nearly the end of April, an interval of about four and a half months, and they are very rare after the middle of November.

The summer monsoon is found to be the stormiest time in the Bay of Bengal. But the storms are restricted to the north of the Bay and to the coasts of Orissa and Bengal. During the pre-monsoon period, the storms are generally confined to the southern parts of the Bay of Bengal.

The rate at which most of the storms in the Bay of Bengal move does not exceed, as a rule, from 4 to 8 miles an hour. The highest rate recorded, abont 14 to 15 miles, is in the post-monsoon period.

There is marked distinction in the character of the weather to north and south of a cyclone in the Bay of Bengal. Cyclones are generated and fed by the damp stormy south-west wind that blows from the equatorial sea and when it prevails right up the bay, is known as the south-west monsoon. Hence, whenever a cyclone is in the process of formation, or is travelling across the bay, this wind prevails everywhere to the south of the storm, and as a south or south-east gale far too eastward of the centre. For a distance of 400 to 500 miles in these directions the weather is squally and rainy with strong winds, and these conditions continue until the storm is exhausted or has reached the land and travelled far inland. But beyond some distance to the west and north-west, the weather remains fine, often calm and sultry, especially during the formation of the storm.

## The Arabian Sea Storms

The stormy season is less definitely restricted than in the Bay of Bengal. There is a greater proportional frequency of storms in the Arabian Sea in May and June than in the Bay of Bengal. There are practically no storms in the Arabian Sea in the months of October and November.

Most of the storms raging in the Arabian Sea are those that have crossed the Indian peninsula from the Bay of Bengal. The cyclonic storms generated in the north of the Bay of Bengal during the summer monsoon, as a general rule, break up and disappear after a more or less protracted course over the land, but some traverse the whole width of Central India to Kathiawar and Cutch, and thence pass out to the extreme north of the Arabian Sea.

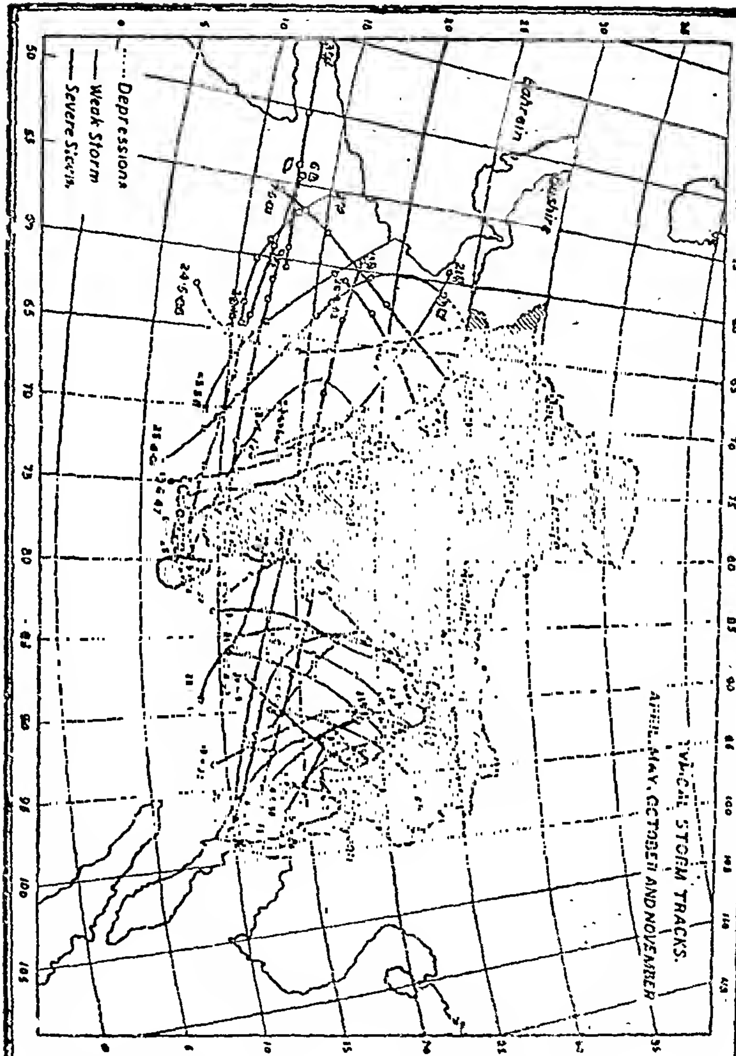


Fig. 48. Storm Tracks.

The map on this page shows the storm tracks in Indian seas.

## Contrast Between Tropical and Temperate Cyclones

There is practically no essential difference between the tropical cyclones and the temperate cyclones or depressions, as the latter are often called. There are only minor differences. These are :—

(1) The temperate cyclones have a much larger diameter than the tropical cyclones.

(2) The barometric gradients are very much weaker in the temperate cyclones than in the tropical cyclones.

(3) The isobars in the temperate cyclones are not circular ; they are often V-shaped. The isobars of the tropical cyclones are nearly more symmetrical and circular.

(4) In the temperate cyclones there are marked temperature differences between the front portion of a cyclone and its rear. In the tropical cyclones the temperatures are the same in every direction. This is because unlike tempera'e cyclones, in tropical cyclones there is no great interplay of air masses with different temperatures and humidity.

(5) Tropical cyclones occur in the warmer half of the year, while temperate cyclones occur, throughout the year being more numerous in winter rather than in summer.

(6) Minor differences are the fact that tropical cyclones are not followed by anti-cyclones, and that they are mostly an oceanic phenomena, dying out rapidly when they move over land. As such the effects of tropical cyclones are felt only near the seacoast.

## Middle Latitude Cyclones

There is a very great disparity in the distribution of air pressure in the middle latitudes. This disparity is greater in the northern than in the southern hemisphere. The reasons for it are obvious. The larger land mass in the middle latitudes of the northern hemisphere, the presence of unusually warm waters owing to warm ocean currents, and the proximity of the greatly disturbed 'Horse Latitudes' are some of these reasons. Under these circumstances, the greatest and the most widespread activity of the atmospheric disturbances is to be found in the middle latitude. The middle latitude atmospheric disturbances are either the cyclones or anti-cyclones.[1] The presence of an 'anti-cyclone' in association with the cyclone, is a special feature of the middle latitudes.

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[1] 'Cyclones' and 'anti-cyclones' are the names given by Piddington and Sir Francis Galton respectively, to two distinct types of closed isobars on the weather map. The circular isobars round a low pressure are called 'the cyclone' and those round a high pressure called 'the anti-cyclone'. The middle latitude cyclones are commonly referred to as 'depressions'.

Humphreys[3] classifies the middle latitude cyclones according to their causes, as follows :—

(*a*) Thermal,

(*b*) Insolational,

(*c*) migratory.

(*a*) Thermal cyclones are caused by the relatively warm water. The system of winds of any region over which the barometric pressure is lower than for the surrounding region is described as semi-permanent cyclone or thermal cyclone. There are several semi-permanent cyclones in existence in various parts of the world. The most important of these is the one that lies south-east of Greenland and south-west of Iceland. This is active at all seasons and produces many travelling cyclones. The other is the Aleutian low, which lies along the south and south-east of the Aleutians, extending over the Gulf of Alaska. The Norwegian Sea and the Sea of Okhotsk are the minor areas. These regions are active during winter only.

In the southern hemisphere the regions of cyclones are the Ross Sea and the Weddell Sea.

All these regions have warmer temperatures than those of the neighbouring areas. The air circulation induced by such temperature distribution is converted into a system of cyclonic winds by the deflective force of the earth's rotation. The warm waters off the coast of Greenland and Iceland, necessarily maintain the atmosphere above at higher temperatures, level for level, than that of the neighbouring icecaps. Hence a practically continuous overflow of air from the one place, with compensating drainage and inflow from the other is enforced by the existing and perpetually maintained distribution of unequal surface temperatures. These temperature contrasts are most pronounced in the case of the 'Icelandic Low' which is most active during winter. But it prevails through summer also for the simple reason that the necessary temperature gradients, though weakened now, are not obliterated ; the water remaining always warm in comparison with the icecaps of both Greenland and Iceland, which persist from season to season and from year to year The 'Aleutian Low', on the other hand, is merely seasonal. It prevails only while the adjacent Alaskan and Siberian regions are snow-covered.

(*b*) Insolational cyclones are of land origin. Just as the gulfs and seas flanked by relatively cold land areas produce thermal cyclones, so also the peninsulas flanked by relatively cold water generate cyclonic wind systems. Such cyclones are also produced when any area of sufficient size becomes heated, through insolation, to temperatures above those of the adjacent regions. The Iberian

2Humphreys, *Physics of the Air.*

Peninsula and the Alaskan Peninsula show this tendency during summer.

(*c*) Migratory cyclones have been the subject of considerable study. From 1850 to 1915 it was generally believed that these cyclones were caused by thermal convection and maintained largely by the latent heat liberated on condensation. These causes have been shown now to be inadequate by the following facts:—(*a*) cyclones are more numerous during winter than during summer; (*b*) occasionally a well-developed cyclone is accompanied by little or no precipitation; and (*c*) sounding balloon records have shown that the temperature of the troposphere in the cyclones in some cases is lower than that of the anti-cyclone made at first to consider the physical processes connected with the origin of these isobaric shapes. The origin of these depressions and the anti-cyclones baffled the meteorologists for long, and it was only about the beginning of this century that ideas became clarified.

The modern theory of the origin of cyclones and anti-cyclones in the middle latitudes is based on the existence of two different types of air masses flowing side by side. In the case of the middle latitudes in the northern hemisphere, the two main classes of air are the polar air in the north and the tropical air in the south. The polar air is defined as the one that originates in the higher latitudes and travels southward. The heating of the lower layers of the air by contact with the earth's surface, in the comparatively lower latitudes, produces a tendency to instability in these layers. This instability gives rise to turbulent mixing.

The tropical air, on the other hand, is the one which originates in low latitudes and travels poleward, and whose temperatures decrease with increasing distance from the equator. The cooling of the lower layers produces stratification in the surface air.

Helmholtz was the first to draw attention to the existence of two such air masses with differing temperatures and differing velocities flowing side, separated only by a *surface of discontinuity*. Systematic observations of these currents were, however, first made by Sir Napier Shaw* in England. But the credit of formulating a theory on this subject goes to the Norwegians. This theory of the formation of depressions is known as the 'Polar Front' theory and was worked out on its mathematical side by Prof. V. Bjerknes and applied with great ingenuity to the analysis of synoptic charts and the practical problems of weather forecasting. Before the development of the Polar Front theory, the rules formulated by the Hon. Ralph Abercromby in his "Principles of Forecasting" were followed for weather forecasting in England and elsewhere.

*Shaw and Lempfert, *Life History of Surface Air Currents*.

## Polar Front Theory

Bjerkne's theory is briefly as follows :—

The polar regions are covered by a mass of cold air, and the tropical regions by a mass of warm air. There is not a continuous change from the cold air to the warm air, but the two masses are separated by a surface of discontinuity—the *polar front*.

Cyclones develop at this surface of discontinuity and constitute the mechanism by which interchange takes place between the cold air and the warm air. Each cyclone consists of two sectors, a warm sector of tropical air and a cold sector of polar air. The warm air pushes the cold air in front of it, and at the same time rises over the cold air, the cold air behind the warm sector pushes underneath the warm air, so that normally the warm sector is being reduced in area and is lifted upwards.

In the inner area of the cyclone, the cold air may, and often does, get right round, with the result that the warm sector is cut in two. The cyclone itself then begins to diminish in intensity. The result is a transposition of the polar front; and a new cyclone, or *Secondary*, usually forms with the remainder of the warm sector and the transposed polar air as its constituents.

The diagrams on page 110 illustrate the development of a middle latitude cyclone. The first diagram *A* represents a portion of the undisturbed polar front, *B* represents the distortion of the front by the warm air pushing northward, diagrams *C*, *D*, and *E* are other stages in this distortion. Diagram *F* shows the disappearance or the 'occlusion' of the depression, and the diagram *G* shows the formation of a secondary depression.

The stage represented by the diagram *D* above has been reproduced in Fig. 50 on a larger scale. *It shows a well-marked depression centred at the most northerly point of the tongue of the warm air.* It moves eastwards with the warm current. The polar front lying at the eastern edge of the warm air is called the *warm front* and the part along the western edge as the *cold front*.

At the top of the main diagram is given an east-west section of the part lying to the north of the trajectory or the path of the centre of the depression. At the bottom is a similar section for the southern part of the depression.

Instead of referring the phenomena of the cyclone to the centre as a single point of reference, the modern theory (Polar Front theory) divides the cyclonic area into two portions, very unequal parts, by two lines which meet at the centre. These two lines mark the boundary of the projection of warm air, generally from the southward, into a region of cold air. Thus the whole area of the cyclone is divided into a warm sector and the cold remainder, instead of being

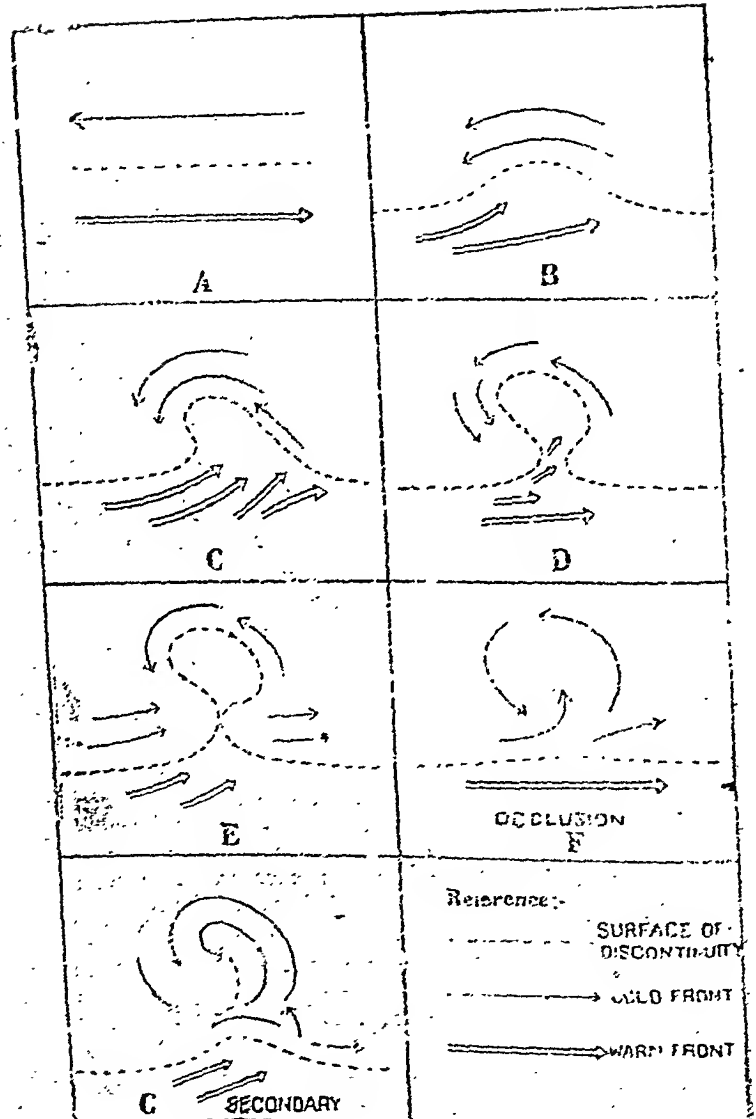



Fig. 49. Development of a Cyclone.

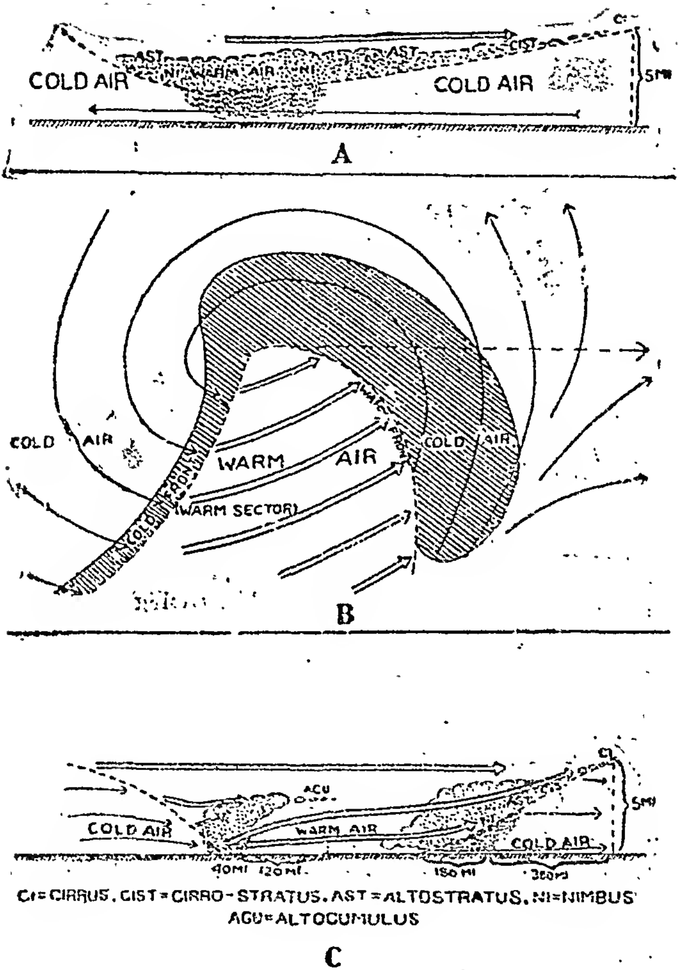



Fig. 50. Structure of a Cyclone.

divided as in the analysis of Abercromby, into front and rear and further subdivided into right and left quadrants.

The dividing line of the cyclone from the centre towards the eastern or advancing side, as has been pointed out above, is called the 'warm front.' In normal conditions it is marked by a rise of temperature, preceded by a succession of clouds. The boundary at

the rear is called the 'squall line' or the 'cold front'. It corresponds with the trough of the depression, and is marked by a sudden fall of temperature accompanied by a slower rain.

This new analysis marks a considerable advance in that it takes account not only of the distribution of cloud and weather, but also of the changes of temperature and the local distribution of rain. The rain in advance of the warm front is attributed to the general accent of warm air from the line of the front, along a slope of about 1 into 100, over the bank of cold air. The rain of the cold front is attributed to the undercutting of the warm air by the cold air in its rear, with a somewhat steeper surface of separation. Rainfall in regions outside those associated with the two fronts is attributed to the local instability of air passing over warm areas.

## Weather in a Cyclone

As is obvious from figure 50 C the depression consists essentially, in its lower part, of two opposing air currents, a cold current and a warm current. These two currents are separated by two lines, both starting from the centre, one the *line of direction* or the warm front line and the other the *squall line* or the cold front line. It is the contact between these differing currents or the prevalence of any one of them that produces the contrasting weather from one moment to the other during the passage of a cyclone. The cold air lying to the east of the depression acts as a high ground as Bjerknes says, against which strike the warm and moist air currents from the south. On the other hand, the cold air at the back of the depression tries to undercut this warm air from behind. At the points of contact between the cold and warm air occur clouds and rain. At other points, warm or cold weather prevails according to the air current prevailing.

It is evident from figure 50 C that the sequence of events on the passage of a cyclone, is the passage of the warm from front, followed by the warm sector, and finally the cold front.

The approach of the warm front is indicated by cirrus clouds, 700 to 1000 miles in advance. As the warm front advances the clouds lower to alto-stratus and nimbo-stratus, and precipitation is common. The rain stops on the actual passage of the front. The passage of the front is marked by falling pressure, increased humidity and a sharp rise of temperature on the actual passage of the front. Then comes the warm sector, in which there is a decrease in cloudiness and constant high temperature. The warm sector gives way to the cold front marked by sudden showers of short duration and vigorous wind shifts. The cloud forms are alto-cumulus and cumulo-nimbus. The actual passage of the cold front is marked by a sharp rise in pressure and an increase of temperature.

As a cyclone approaches easterly winds set in, with the passage of the cyclone, these winds shift clockwise from south-east to south-west, to west, to north-west. Thus veering winds mark the passage of a cyclone.

The following table and Fig. 51 give an idea of the weather in a depression.

TABLE

| | Wind | Pressure | Temperature | Rainfall |
|---|---|---|---|---|
| Warm Front | South-East to South | Falling | Sharp Rise | Steady Drizzle |
| Warm Sector | South-West | Steady | Steady | ... |
| Cold Front | West to North-West | Rising | Fall | Short Sudden Showers |

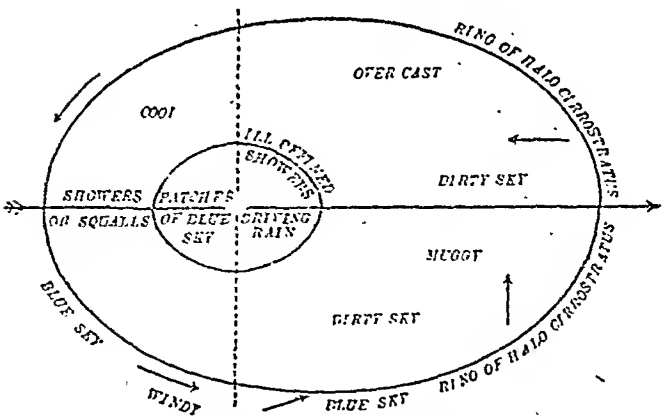



Fig. 51. Weather in a Depression.

## Most Frequented Areas

The belts of the westerlies, both in the northern and the southern hemisphere, are the most frequented areas of the middle latitude depressions. The frequency is the greatest where the temperature contrasts are the greatest. The North Atlantic Ocean is one such area, for here the warm Gulf Drift passes just south of the ice-

covered Greenland. The depressions follow each other at short intervals across the North Atlantic towards Europe, especially in winter. A somewhat similar area is found in the North Pacific near the Aleutian Islands from where the depressions move towards North America.

In the southern hemisphere the depressions are active throughout the year, both during the summer and the winter, owing to the presence of a stable and intense anti-cyclone over Antarctica throughout. The path followed by the depressions in the southern hemisphere coincides with the sub-polar low pressure belt.

The centres of low pressure move about more or less irregularly, but almost invariably from west to east in the higher latitudes. They are usually generated over oceans, and because a supply of moist air is essential for their continued existence, they tend to keep to the neighbourhood of water masses, or if that is not possible, of large river valleys. Since anti-cyclones develop over land masses in winter, the paths of depressions are restricted, on this account also, to the neighbourhood of the oceans during winter. The depressions tend to avoid the anti-cyclonic high pressure areas, moving from west to east on the polar side of a large anti-cyclone and from east to west on the equatorial side. For all these reasons the paths of depressions are intimately connected with the distribution of land and sea.

The following map gives the generalised paths followed by the depressions :—

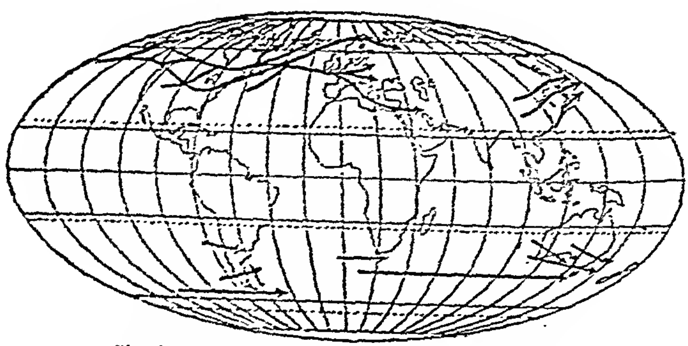


Fig. 52. Most Frequented Paths of Depressions.
[After *Knight*]

## Anti-cyclone

The anti-cyclone gives another closed isobaric shape on the weather map. It is, however, opposed to the cyclonic isobars in that it encloses a high pressure area. An anti-cyclone is a centre of

high pressure in which, in the northern hemisphere, the wind circulates *clockwise* around the centre. It is a centre of *diverging winds.* This divergence is due to the accumulation of air at high levels, causing a general settling down at low levels, with a gradual movement outwards from the centre.

Hanzlik discovered from his study of the European anti-cyclones that there are two distinct types of anti-cyclones; the cold anti-cyclone and the warm anti-cyclone.

The cold anti-cyclones of Europe and America are the counterpart of the preceding depression. They are generated by the cold currents from polar regions which follow southward in the rear of a cyclone. The warm anti-cyclones are much deeper structures than the cold anti-cyclones. They are areas into which air is descending from much higher levels in the stratosphere. The descending air causes them at the lower levels to be warmed by compression.

The weather associated with an anti-cyclone is generally dry. The 'cold-waves' and 'heat-waves' often accompany anti-cyclones. Winds in the anti-cyclone are light and variable. Anti-cyclones show little energy and often remain in one spot for days or even weeks at a time. Strong winds are never found in their central parts. Rain seldom falls in a well-marked anti-cyclone. This does not necessarily mean a cloudless sky. There are some anti-cyclones which have clouded skies and others which have clear skies. A winter cyclone is frequently a region of dull skies and fogs.

Our knowledge about anti-cyclones is even less complete than of the cyclones. According to Brunt* much of the discussion about anti-cyclones is 'rather of the nature of guess work.'

### Temperature and Rainfall Distribution In North America

As North America is nearly all within the middle and northern latitudes, it has a large central area in which the continental type of climate with marked seasonal temperature extremes is found.

Along the coasts of northern Alaska, western Canada, and the north-western part of the United States, moderate summer temperatures are in marked contrast to those prevailing in the interior, east of the mountains. There is a southward dip along the coast. Again, the mild winter temperatures in the coastal areas stand out against the severe conditions to be found from the Great Lakes northward and north-westward.

In the West Indies, temperature conditions are subtropical; while in Mexico and Central America, climatic zones depend on elevation, ranging from subtropical to temperate in the higher alti-

* Brunt, *Physical and Dynamical Meteorology*, p. 381.

tudes. The prevailing westerly winds carry the continental type of climate eastward over the United States, so that the region of maritime climate along the Atlantic Ocean is very narrow.

The northern part is, of course, very cold; but the winter low temperatures are not so low as in north-eastern Siberia, where the vast extent of land becomes much colder than the partly ice-covered area of northern Canada.

From the Aleutian Peninsula to northern California west of the mountains, there is a narrow strip where annual precipitation is over 40 inches. It exceeds 100 inches locally on the coast of British Columbia. East of this belt there is an abrupt decrease in precipitation to less than 20 inches annually over the western half of the continent from lower California northward, and to even less than 5 inches in parts of the Great American Desert, in the south-western part of the United States.

From the south-eastern part of the United States north-eastward to Newfoundland, the average annual precipitation is more than 40 inches. In the West Indies, southern Mexico, and Central America rainfall is generally abundant, though very spotty. It varies widely even within short distances, especially from the windward to the leeward sides of the mountains.

## In South America

A large part of South America lies within the Tropics and has therefore a tropical climate. But the remaining narrow southern portion is not subject to the extremes of heat and cold that are common in North America or Asia. Temperature anomalies unusual for a given latitude are found mainly at the elevated levels of due to high altitude.

The Antarctic Current and its cool Humboldt branch skirting the western shores northward to the Equator, together with the prevailing on shore winds, exert a strong cooling influence over the coastal regions of South America. On the east coast the southerly moving Brazilian current from tropical waters has the opposite, or warming, effect except along southern Argentina.

In the northern parts of South America the sharply contrasted dry and wet seasons are related to the regime of the trade winds. In the dry season (corresponding to winter in the Northern Hemisphere) these winds sweep the entire region, while in the wet season (corresponding to summer in the Northern Hemisphere) calms and variable winds prevail. In the basin of the Amazon river the rainfall is related to the equatorial belt of low pressure and to the trade winds, which give the maximum amounts of rainfall in the extreme west, where they ascend the Andean slopes.

The desert area on the west coast of South America, extending from the Equator southward to the latitude of Santiago, are due primarily to the cold Humboldt or Peruvian Current and upwelling of cold water. The moist cool ocean air is warmed in passing over the land, with a consequent decrease in relative humidity, so that the dew point is not reached and condensation of vapour does not occur until the incoming air has reached high elevations in the Andes, where temperatures are very much lower than along the coast.

In southern Chile the summer season has only moderate rainfall, but winters are excessively wet. The conditions that prevail farther north are not present here, and condensation of moisture from the ocean progresses from the shores up to the crests of the Andes. By the time the air passes these elevations, however, the moisture has been exhausted and the winds on the leeward slopes are dry, becoming more and more so as they are warmed on reaching lower levels. The Andes mountains thus produce a great 'rain shadow' over southern Argentina.

### In Europe

In Europe there is no extensive north-south mountain system such as is found in both of the Americas, and the general east-west direction of the ranges in the south allows the conditions in the maritime west to change rather gradually toward Asia. Generally rainfall is heaviest on the western coasts, where locally it exceeds 60 inches annually and diminishes toward the east, except in the elevated Alpine and Caucasus regions, to less than 20 in. in eastern Russia. There is a well-defined 'rain shadow' in Scandinavia, with over 60 inches of rain in western Norway aud less than 20 inches in eastern Sweden.

Over much of Europe rainfall is both abundant and evenly distributed throughout the year. The chief feature of the seasonal distribution of precipitation is the marked winter maximum and the extremely dry summers in most of the Mediterranean lands.

Isothermal lines have the general direction of the parallels of latitude, except in winter; when the waters of the western ocean, warmed by the Gulf Stream, give them a north-south trend. Generally, there are no marked dips in isotherms due to elevation and continental type of climate such as are found in North America. In Scandinavia, however, the winters show an abrupt fall in temperature from the western coast of Norway to the eastern coast of Sweden.

### In Asia

The vast extent of Asia gives full opportunity for continental conditions to develop a cold area of high barometric pressure in

winter and a low-pressure, hot area in summer, the former north-east of the Himalayas and the latter stretching widely from west to east in the latitude of northern India. These distributions of pressure give to India the well-known monsoon seasons, during which the wind comes from one direction for several months, and also affect the yearly distribution of rainfall over eastern Asia.

In winter the air circulation is outward over the land from the cold pole, and precipitation is very light over the entire continent. In summer, on the contrary, there is an inflow of air from the ocean. Even the south-east trade winds flow across the Equator and merge into the south-west monsoon which crosses India. This usually produces abundant rain over most of that country, with excessively heavy amounts when the air is forced to rise, even to moderate elevations, in its passage over the land At Cherrapunji, (4,455 ft.) on the southern side of the Khasi Hills, in Assam, the average rainfall in a winter month is about 1 inch, while in both June and July it is approximately 100 inches.

North of the Himalayas the winters are excessively cold though temperatures rise in summer fairly high. At Verkhoyansk in the cold pole area, and north of the Arctic Circle, the mean temperature in January is about 59 F. and in July approximately 60°. The extreme records are a maximum of about 94° from readings at 1 p. m., and a minimum of 99°F.

In south-western Asia also the winter temperatures are generally low, especially at high elevation; in summer at low elevations excessively high maxima are recorded, as, for example, in the Tigris-Euphrates Valley.

## In Africa

Africa, like South America, lies very largely within the Tropics; and there too, temperature distribution is determined mainly by altitude. Moreover, along the southern portion of the western coast the cool Benguela Current moves northward. On the eastern coast are the warm tropical currents of the Indian Ocean. These currents cr ate conditions closely paralleling those found around South America. In the strictly tropical areas of Africa conditions are characterised by prevailing low barometric pressure, with convectional rainfall and alternate northward and southward movement of the heat equator; while in both the north and the south the ruling influences are the belts of high pressure.

Except in the Atlas Mountains where the high elevations set up a barrier in the path of the trade winds and produce moderate rainfall, the desert conditions typified by the Sahara, extend from the Atlantic to the Red Sea and from the Mediterranean southward well beyond the Tropic of Cancer.

South of the Sahara, rainfall increases rapidly, becoming abundant to heavy from the west coast to the central lakes with annual maxima of over 80 inches in the regions bordering the eastern and western extremes of the Guinea coast. This marked increase in rainfall does not extend to the eastern interior where the annual amounts received are below 40 inches. Rainfall decreases to less than 10 inches on the coasts of Somaliland. Also to the south of the central rainy area there is a rapid fall toward the arid regions of South-west Africa, where conditions are similar to those in Somaliland.

Heavy rain falls over sections of Ethiopia from June to October. more than 40 inches and brings the overflowing of the otherwise arid Nile valley.

Moist equatorial climate is typified in Africa by conditions in the Belgian Congo; arid torrid climate by those of Egypt and the Sahara, and moderate plateau climate by those found in parts of Ethiopia and the British possessions to the southward.

### In Australia

In the southern winter the high-pressure belt crosses the interior of Australia, and all except the southernmost parts of the continent, are dry. In summer, on the other hand, this pressure belt has moved south of the continent, still giving dry conditions over the southern and western areas. Thus the total annual precipitation is less than 20 inches except in the extreme south-west and in a strip circling from south-east to north-west. The average annual precipitation is even less than 10 inches in a large south-central area of Australia.

In the south the winter precipitation is of the cyclonic type; the heavy summer rains of the north are of monsoon origin; and those of the eastern borders are in large part orographic, owing to the presence of the highlands in the immediate vicinity of the coasts. In the outer or seaward border of the rainfall strip along the coastal region, the mean annual rainfall is over 40 inches and in many localities over 60 inches. This is true also for the monsoon rains in the north.

Because of the location of Australia, on both sides of the Tropic of Capricorn, temperatures far below freezing are to be found only in a small part in the south at high elevations. In the arid interior, extreme maximum temperatures are very high, ranking with those of the hottest regions of the earth.

CHAPTER VIII

# ATMOSPHERE—(*continued*)

THE WEATHER MAP—SYNOPTIC CHARTS—SYNCHRONOUS CHARTS SHAPES OF ISOBARS—WEATHER IN INDIA

## The Weather Map

The repetition of the atmospheric conditions as regards temperature, rain or winds is rendered uncertain by the appearance of atmospheric disturbances in the shape of cyclones or anti-cyclones. This uncertainly affects the temperate regions, which are dominated by the westerlies, more than the tropical regions where there is a certain amount of steadiness in the changes in the atmosphere. Owing to this uncertainty caused by the cyclones and anti-cyclones in the temperate regions, one day's weather conditions are seldom repeated the next day.

Human activities are so intimately related to the weather conditions, that it is an advantage to know beforehand what the weather is going to be tomorrow, so that one may be ready for it. Weather forecasting has, therefore, come to occupy an important place in the world's affairs today. The weather forecaster needs, in order to discharge his duties satisfactorily, a weather map of the world or the area around him. This map becomes necessary, because the art of weather forecasting is based on the dictum that 'the weather travels.' What weather one place has today the other place is going to have tomorrow. It is, therefore, necessary to know the weather prevailing in the adjoining area, as well as, in the far-off areas. It is interesting to note that though the need for the weather map existed for a long time, serious efforts to produce the weather map were made only during the last Great War for strategic purposes.

A weather map has been defined as a 'delineation of the weather over a portion or the whole of the earth on a flat surface of paper or other material'.[1] The term weather has a somewhat special meaning. It is employed by the meteorologists to denote the state

of the sky and whether there is precipitation in the form of rain, or absence of precipitation. In its broader sense it may refer to the state of the sky, the occurrence or absence of precipitation, the temperature humidity, air pressure and wind. The daily weather map is compiled from data supplied by numerous observatories situated over most of the world. There are 600 such observatories over Europe alone. Besides these, every ship on the ocean must take these observations. There are international agreements for the supply of weather data to different countries. These data are communicated to a central office in every country where they are collated and maps are made. By international agreement these observations must be made at fixed hours, and communicated by the quickest method. These communications give a synopsis in a fixed form of the weather conditions prevailing at fixed times. It is from these 'synoptic messages' of weather that *synoptic charts* are prepared. Weather forecasts are made from synoptic charts. The synoptic chart is a map of the geographical region under consideration showing the distribution of meteorological elements for the same point of time or for the same period of time. The synoptic charts for the same point of time are called *synchronous charts* and are the main charts used in the forecasting of weather.

The synoptic messages are sent in abbreviated letters standing for certain weather phenomena, and the synoptic charts use these letters as well as certain special signs. When the intensity of a certain phenomenon is to be emphasised a capital letter, instead of a small letter is used. Similarly, when continuity of a certain phenomenon is to be indicated the letter is repeated. These abbreviations are called the Beaufort Letters and are given in Fig. 53.

From the data received at the central stations, isobars, isotherms and isohyets are prepared. These lines of equal value of the several meteorological phenomena enable the observer to get at a glance the generalised picture of the weather prevailing in a certain area at a certain time. The basic lines are, however, the isobars. For these are the isobars which indicate the direction in which the atmospheric circulation will move, and with it the weather. The weather moves with the movement of the atmosphere. Isobaric lines give the condition of the barometer that the weather forecaster looks. All other lines are, therefore, of secondary importance to him. A weather map often shows only the isobars, the wind velocity, and the amount of rain.

It is noticed that under certain types of weather, the isobars acquire certain special shapes. The weather forecaster, by familiarising himself with these shapes, is able to forecast the type of weather that is going to follow. A description of these shapes is given on page 122.

### THE BEAUFORT LETTERS AND INTERNATIONAL SYMBOLS

(1) Appearance of Sky.

| | | |
|---|---|---|
| b | | Blue sky whether with clear or hazy atmosphere. |
| c | | Cloudy, i.e., detached opening clouds. |
| o | | Overcast, i.e., the whole sky covered with one impervious cloud. |
| g | | Gloom. |
| u | | Ugly, threatening sky. |

(2) Wind

| | | |
|---|---|---|
| q | | Squalls. |
| KQ | | Line squall. |

(3) Precipitation.

| | | |
|---|---|---|
| r | ● | Rain. |
| p | ▽ | Passing showers.* |
| d | , | Drizzle. |
| s | ✱ | Snow. |
| rs | ●✱ | Sleet. |
| h | ▲ | Hail. |

(4) Electrical Phenomena.

| | | |
|---|---|---|
| t | | Thunder. |
| l | < | Distant lightning. |
| tl | R | Thunderstorm. |

(5) Atmospheric Obscurity and Water Vapour.

| | | |
|---|---|---|
| f | ≡ | Fog } Range of visibility less than 1,100 yards. |
| fe | | Wet Fog } |
| z | ∞ | Haze, range of visibility 1,100 yards or more, but less than 2,200 yards. |
| m | = | Mist, range of visibility 1,100 yards or more, but less than 2,200 yards. |
| v | 0 | Unusual visibility of distant objects. |
| e | | Wet air, without rain falling. |
| y | | Dry air (less than 60 per cent humidity). |

(6) Ground Phenomena.

| | | |
|---|---|---|
| w | ⌂ | Dew. |
| x | ⊔ | Hoar-frost. |

Fig. 55

### Shapes of Isobars

The isobars may group themselves into the following shapes :—

(i) cyclone, (ii) anti-cyclone, (iii) straight isobars, (iv) secondary depression, (v) V-shaped depression, or (troughs of low pressure), (vi) wedge-shaped isobars, and (vii) col.

(i & ii) The following are the shapes of isobars associated with cyclones and anti-cyclones. The weather associated with these shapes has already been described in a previous chapter.

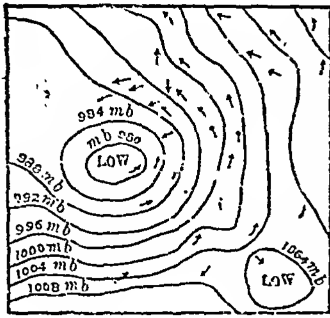



Fig. 54. Cyclone.

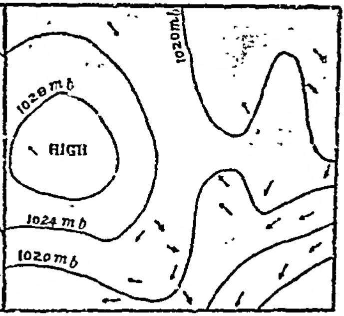



Fig. 55. Anti-cyclone.

(iii) Straight isobars represent an intermediate region between a cyclone and an anti-cyclone both of vast area. There is usually a uniform gradient. A great variability of weather is an important feature. Varieties of weather under straight isobars are most perplexing to the meteorologists.

Fg. 56. Straight Isobars.

(iv) Secondary depression is a name given to any distortion of the symmetry of the isobars which may be represented merely by a sinuosity, or

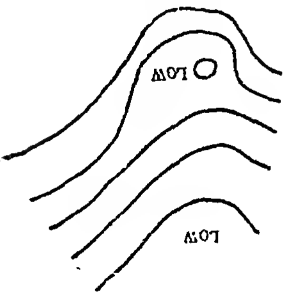


Fig. 57.
Secondary Depression.


Fig. 58.
Sinuosity of Isobars.

sensible deviation from the symmetrical run of the isobars with corresponding alterations in the direction of the wind. The secon-

dary has not yet been fully understood by the meteorologists. The secondaries may form in any part of the main depression, but they seem to reach their greatest development on the southern side. General tendency of Secondaries is to move in a counter clockwise direction round their Primaries.

The passage of a secondary is often attended by rain squalls, or even thunderstorms.

(v) The transitional stage between the mere sinuosity in the isobar and the detached and almost independent centre of a satellite depression, is aptly called the V-shaped depression or Trough of Low Pressure, because a series of isobars have that shape and it is easily recognisable.


Fig. 59. V-Shaped Isobars.
(Trough of Low Pressure)

Sudden changes are characteristic of V-shaped depressions, because the troughs may be either warm fronts, cold fronts or (occulsions when no warm air remains in the depression). If the front is moving slowly, as in an elongated V, the improvement in weather is correspondingly slow.

The V-shaped is generally acquired by the depressions on their equatorial side. This shape is most frequent in the United States of America and in Europe and represents immature or undeveloped cyclones within larger cyclones from which 'secondaries' are often formed.

(vi) When an anti-cyclone thrusts itself between two 'lows' we have a wedge ; very much the inverse of a V-shaped depression as regards winds.

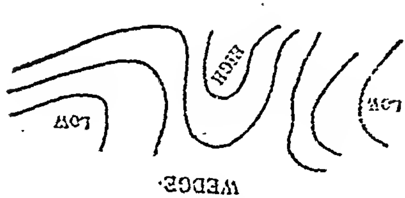


Fig. 60.

The wedge is often associated with a brilliant weather. This fine weather is, however, of short duration and soon gives place to the cloud and rain of the depression on its western flank.

(vii) The saddle-shaped isobars between two 'lows' and two 'highs' are known as the 'col'. Its weather is of a very dubious character. The absence of any pressure gradient in the central region leads to calms or light air, and these develop fog in winter, and

thunderstorms in summer, if there is enough moisture in air. Cold seldom remains for long.

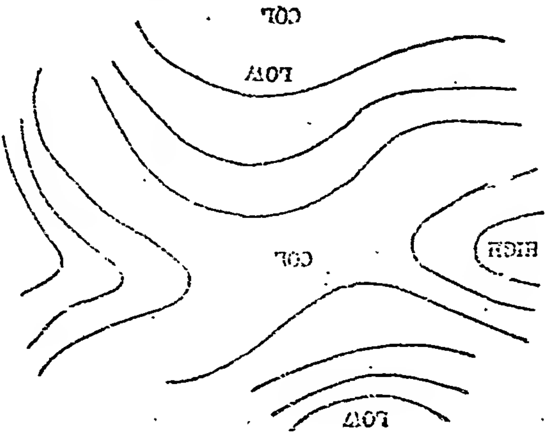



Fig. 61

The different portions of a cyclonic area present different general characteristics. The front and the rear of a V-shaped depression present almost opposite characteristics.

## Weather in India

The weather map of India is a simple affair, compared with the temperate regions where the influence of the atmospheric disturbances is most marked. The general prevalence of a fine, dry, weather during the cold season : and of a rainy and stormy weather during the summer are the two important characteristics of the Indian weather.

During winter, Northern India remains, for weeks together, a region of high pressure. This high pressure is, however, not quite stable. Now and then a depression invades it, displacing it entirely or partially. The origin of these depressions is not yet understood completely. Some of them are formed in the north-western parts of India or even farther south. Others come into India probably from the Mediterranean Sea. All these cold weather depressions move generally in an easterly direction.

Apart from these depressions, there are certain barometric surges common to all parts of India both during winter and during summer. These surges are more marked in Northern India than in Southern India. The following diagram gives these surges for some stations in India :—

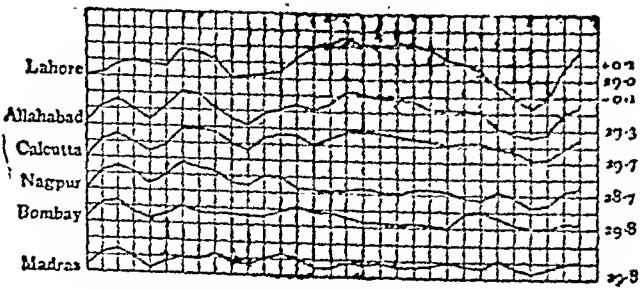



Fig. 62. Barometric Surges During a Month.

These surges are independent of any cyclone or anti-cyclone that may be lying over the country. The weather changes associated with them are generally of a local character. The rise and fall of the barometer in these surges amount ordinarily from one-tenth to two-tenths of an inch. The falling barometer, while these surges are passing, has a tendency to intensify the weather generally prevailing. During summer, for instance, a fall is associated with


Fig. 63. Anti-cyclonic Weather During Winter.

thunderstorms and dust storms. During winter, on the other hand, easterly and southerly winds are brought which modify the temperatures a little, and may give some rain. During the rainy season, it brings about a very heavy rainfall.

The winter weather in India is, thus, the product of :—

(*a*) Anti-cyclones which cover, for the greater time the north-west of India ;

(*b*) depressions which displace the above anti-cyclones for a short period ; and

(*c*) barometric surges which affect only the local weather.

When the anti-cyclone is lying over the north-west, light north-westerly winds or calms prevail over Northern India, while in Southern India northerly or easterly winds blow. The winds coming from the anti-cyclonic area are dry and cold. They become colder as the year advances. Fig. 63 gives an example of the weather associated with an anti-cyclone.

The distribution of pressure and the winds which accompany this type of anti-cyclone are so characteristic, that the weather chart of one anti-cyclone is almost exactly reproduced in another.

The first appearance of a winter depression is about the end of December or the beginning of January. With the approach of the depression, light southerly wind and a close weather prevails. Then comes the rain. Unless the course of the depression is much to the south, heavy snow falls in the Himalayas. When the depression has passed away, the barometer rises rapidly in the north-west and the cold north-west winds in the north and the easterly winds in the peninsula are established once again.

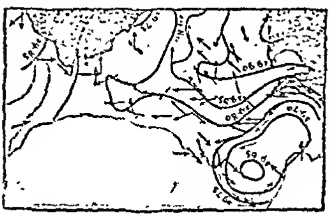


Fig. 64. Winter Depression.

If, however, the depression be formed over western or Central India, it persists for a longer period. There is no snowfall in the Himalayas, and the weather that succeeds the passing of such a depression is not cold. The side map gives an example of the weather associated with a winter depression.

As the year advances and the sun begins to shine overhead, north of the equator, the pressure distribution is gradually reversed. A broad trough of low pressure now runs across Northern India, with the high pressure lying to the south and east of it. The pressure gradient being weak, there are light winds and calms. In the

peninsula, the isobars run more or less, in the direction of the coast, showing that pressure is higher on the adjoining sea than in the peninsula. The winds that tend to move round the low pressure in

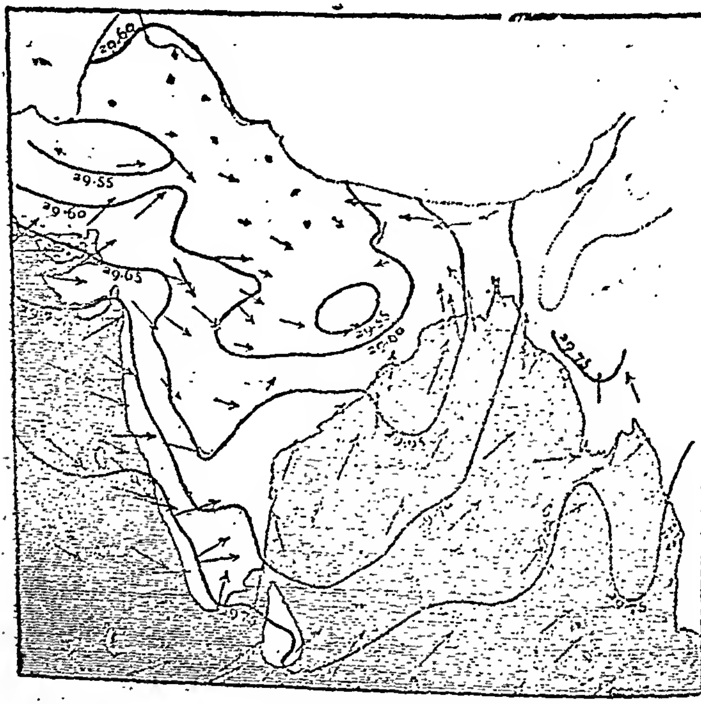



Fig. 65. Average Barometric Condition for May.

the interior of the land are from the south on the east coast and from the west on the west coast and in north-western part of the country. The west winds blowing on the land are dry winds and thus the weather is absolutely dry.

The chief winds of the early part of summer in India are the land winds coming from the north-west. They become less steady as the barometer falls in the Punjab, Sind and the Western Rajputana. But they continue up to the setting in of the south-west monsoon with its rain. The above map for weather conditions in May illustrates this.

Later, the sea winds are able to penetrate far into the interior and the rainy season starts. The hot summer season of northern India, thus alternates between the dry, scorching heat on the one hand, and the damp oppressive heat, relieved now and then by thunder showers or dust storms on the other.

The following maps give an idea of the weather prevailing in early summer :—

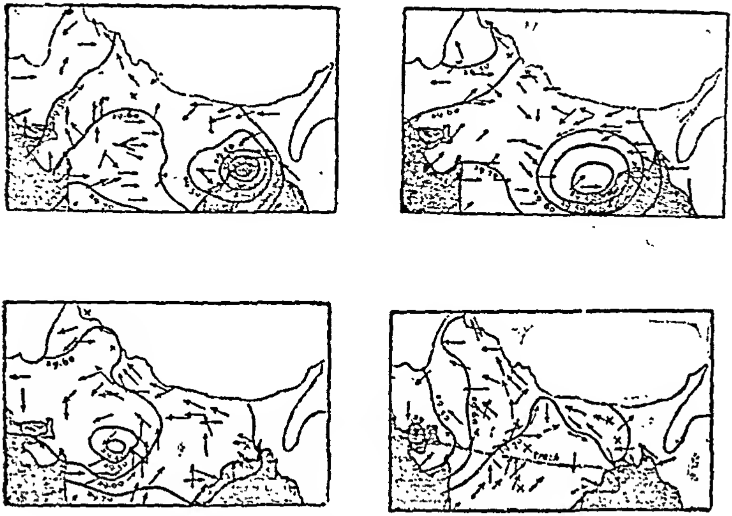
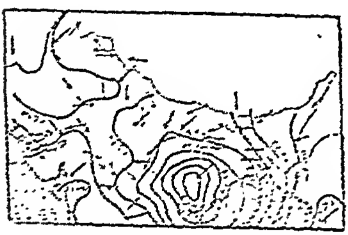


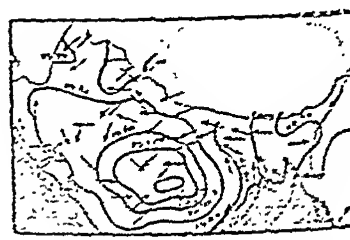
Fig. 66. Rainy Weather in India.

The transition from the hot to the rainy season in India is generally sudden, except in Assam, Bengal and the Arakan coast where the winds coming from the sea during early summer had been giving a few showers. In Bengal, the rainy weather sets in with a small cyclonic storm which starts from the head of the Bay of Bengal with a squally weather, about the middle of June. The rains start earlier in Travancore and Bombay.

The general steadiness of the Indian weather and the simplicity of its weather maps disappear with the advent of the rainy season. This change is first marked by the further intensification of the trough of low pressure in the north-west and the increase of pressure along the coast near Travancore. A comparison between the hot weather map on page 128 and the rainy weather maps on page 124 will show that the bend that marks the isobars in the interior of the peninsula in the former disappears in the latter maps. The isobars in the second map run obliquely from coast to coast. A little depression that lies near the coast of Orissa in the first map has also disappeared in the maps given above. In other words, the stage has been set for the penetration of the sea winds far into the interior of the country. The north-west winds prevailing in Northern India gradually weaken and give place to the east winds from the sea.

The arrangement of the pressure distribution in the maps on page 129 is often complicated by the appearance of cyclones and cyclonic storms at the head of the Bay of Bengal and locally in the area occupied by the trough of low pressure. Heavy rain falls in the wake of these disturbances. Rainfall is also heavy over the eastern part of the trough and in Bengal and Assam, especially during the fall in the barometric surge mentioned above. The cyclonic storms follow a western or north-western path and affect greatly the distribution of rainfall over the greater part of the interior of the country. The following maps trace the progress of two such cyclonic storms, one going west and the other north-west :—





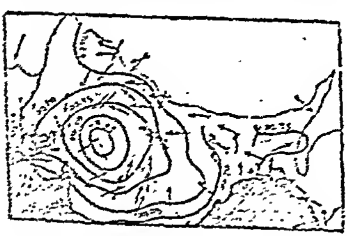


Fig. 67. These maps show the position of the cyclone on different dates. Note that the cyclone has travelled into the interior. The rate of progress is not uniform, depending upon local conditions.

The storms that are formed at the beginning of the south-west monsoon or at its end in the Bay of Bengal, as also those that may be formed during the period of exceptional drought in the interior of the country, take a northerly course across Bengal and do not reach the interior of the country in the west or north-west.

Temporary interruptions in the rainfall distribution owing to the weakening of the monsoon current for a short time are a common feature of the rainy season. But sometimes, these interruptions become serious as they last longer than usual or bring about an abrupt end of the rainy season in the interior of the country. On such occasions a very characteristic change appears in the isobars. The usual northward bend of the isobars in Rajputana and Central India protrudes further north and east, and the obliqueness of the slope of the isobars from west to east is greater. It means that the pres-

sure in Western India is higher than is usual. This characteristic feature of the isobars has been called by the meteorologists as 'the shoulder of high pressure'. Whenever the shoulder of high pressure appears, the easterly winds from the sea cease to blow into the interior and their place is taken by dry north-westerly winds.

The northward displacement of the axis of the trough of low pressure in Northern India to near the foot of the Himalayas is another change that marks such occasion when the rain falls suddenly. The easterly winds that prevail to the north of the trough cannot now enter the northern part of the country. The following map shows these changes :—

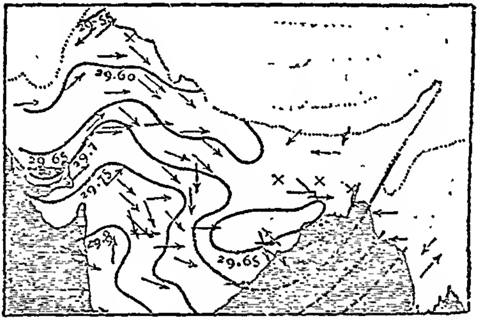



Fig. 68. Shoulder of High Pressure. Such a pressure distribution causes failure of rain in Northern India because the rain-bearing winds cannot penetrate into the high pressure.

With the passing of the sun south of the equator, the temperatures begin to fall in Northern India. The trough of low pressure, therefore, gradually disappears and gives place to the winter anti-cyclone. The monsoons from the Bay, therefore, cannot penetrate into Northern India. From about the middle of October they begin to blow towards the eastern coast of the peninsula and the highest rainfall of the Madras coast is received during the period. The cyclonic storms formed now in the south-west of the Bay of Bengal travel towards this coast giving rainfall.

The summer weather of India is thus, dominated by the trough of low pressure covering Northern India and the cyclonic storms that move from the Bay of Bengal. It is due to these storms that the weather conditions become disturbed and varied during the later part of summer.

CHAPTER IX

# CLIMATE

CLIMATIC TYPES—TROPICAL CLIMATES—TEMPERATE CLIMATES—POLAR CLIMATES—MOUNTAIN CLIMATES—NEW CLASSIFICATION OF CLIMATE—CLIMATIC CHANGES—EFFECT OF CLIMATE ON MAN.

## Climatic types

Based on the differences of climate, the world has been divided into certain climatic regions, where in a given area the points of similarity are the greatest. The division is twofold, horizontal into 'zones', and vertical into 'types'. In the horizontal division the distribution of solar heat has been the guiding factor, while the vertical division has been determined by the influence of prevailing winds as modifying temperature and giving rain.

Starting from the equator towards the poles the horizontal divisions are (*i*) the Tropical, (*ii*) the Temperate, and (*iii*) the Polar. The old Greek geographers fixed certain lines of latitude as the boundary lines of these regions. Thus, the Tropics of Cancer and Capricorn were the boundary lines of the Tropical region and the Arctic and the Antarctic circles were the boundary lines of the Temperate regions. Supan has, however, suggested the isotherms as the dividing lines. He has suggested bounding of the Tropical belt by the two *mean annual isotherms of* 68° F. and of the Temperate belt towards the Poles by the isotherm of 50° F. *for the warmest month.*

## Tropical climates

The tropical and sub-tropical regions have, on the whole, a warm climate. The extremes of temperature occur in the sub-tropical regions, where the summers are the hottest in the world; while the winters are fairly cold. Near the equator, very high temperatures do not occur, but at the same time, except at very high elevations, temperatures below 50° F. are unknown. Roughly speaking, the sun dominates the climates of the Tropical regions, as against the oceanic dominations in the Temperate regions.

The amount of rain varies from a total too small for agricultural requirements to more than 400 inches and comes mostly in summer, except in the equatorial region where it rains throughout the year. The monsoons are the most important feature of the sub-tropical regions. The regular flow of the trade winds, which are the prevailing winds of the tropics, is disturbed by these monsoons. The monsoons are the bringers of rain.

The following table shows the mean annual maxima and minima in different latitudes (average of a number of stations) in the Tropical regions :—*

| Latitudes N. & S. | Max. Temp. (F.) | Min. Temp. (F.) | Cloudiness | Rainfall (") |
|---|---|---|---|---|
| 40°-30° | 98 | 27 | 40 | 24 |
| 30°-20° | 102 | 45 | 34 | 25 |
| 20°-10° | 99 | 59 | 40 | 40 |
| 10°-0° | 97 | 65 | 52 | 68 |

Note carefully that while the highest maxima occur in the subtropical regions between 20 and 30 degrees, the highest minima occur near the equator between 10 and 0 degrees. Note also the steady increase of cloudiness towards the equator.

An important feature of the Tropical climates is the cyclonic activity which is conspicuous because of its destructiveness. The tropical cyclones differ from those of the temperate regions in several respects. Their area is usually less, and their rate of movement higher. The gradient is generally steeper and the winds are, therefore, more violent and the rainfall heavier.†

In general, the tropical cyclones develop on the edge of the belt of equatorial calms. While the great majority of these storms travell in a north-westerly direction towards the coast of Asia, a few take a south-westerly course. On reaching the continent many penetrate inland during the hot months, but during the cold season, when pressure is high over the continent, the storms re-curve in a north-easterly direction, out to the sea again.

The Tropical region falls under the following types :—

(1) Equatorial. (2) Sahara. (3) Savana. (4) Monsoon.

(1) The Equatorial type of climate occurs between (10° N and 10° S of the equator, though on the windward margins of land masses it may spread to 15°.

*Brooks, *Climate*, p. 115.

†See Lake, *Physical Geography*.

Temperature is high throughout the year, averaging 77° to 80°. But more pronounced than the high temperature is the uniformity. The annual range is only about 5°. At Jaluit in the Marshall islands it is only 8° F. This uniformity of temperature follows from the fact that solar insolation is relatively constant. The steadiness in solar insolation is due to the sun being nearly overhead all the year round, and the days and nights varying little in length. The high humidity counteracts the slight variations in insolation. It also checks too high temperatures. There are generally two maxima and two minima of temperature connected with the passage of the sun, north and south of the equator. But exceptions are numerous, and temperature variations are related rather to the variations in rainfall. Thus Lagos, has maximum insolation in August. But temperature is then at a minimum due to August being the rainiest month for Lagos!

The daily range of temperature is quite large when compared to the annual range, being about 15° against the average annual range of about 5° F. For this reason Martonne has said that Nights are the winters of the tropics. Daily extremes of temperature lie about 70° F and 90° F.

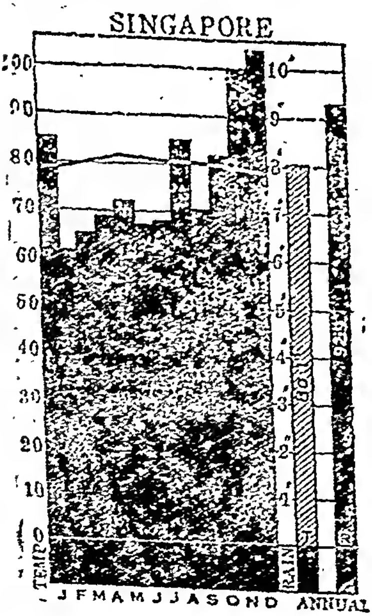



Fig. 69.

The climate is marked by the occurrence of rain almost throughout the year. Rain falls almost every day though some seasons may be more rainy than others, following the passage of the sun across the equator. The rainfall is convectional in nature, is generally heavy and is accompanied by lightning and thunder, but it lasts only a few minutes,* cloudiness is common; about 60% of the days are cloudy. The relative humidity, *i.e.*, the proportion of water vapour in air is high varying about 80%.

In most of the regions with this climate, winds are conspicuously absent, except along some coasts of continents and on islands lying further from the equator where the trade wind belt approaches.

*See page 91.

The following climate data for Singapore are representative of this climate :—

| Months | J | F | M | A | M | J | J | A | S | O | N | D | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp. (F.) | 78·3 | 79·0 | 80·2 | 80·8 | 81·5 | 81·1 | 81·0 | 80·6 | 80·4 | 80·1 | 79·3 | 78·6 | 80·1 |
| Rain (") | 8·5 | 6·1 | 6·5 | 6·9 | 7·2 | 6·7 | 6·8 | 8·5 | 7·1 | 8·2 | 10·0 | 10·4 | 92·9 |

(2) The Hot Desert. The sole criterion of the desert climate is aridity, the essential feature being not the fact that rainfall is low, but the fact that potential evaporation shall exceed precipitation. This climatic type is located about the latitudes 20° or 25° North and South, the chief representative areas being the Sahara, Arogona, South-West Asia, the Atacama, the Kalahari, and Western Australia. These areas as dry because

(*a*) they are regions of dry settling air. This air as it settles down is warmed and hence does not give any rain.

(*b*) they are regions of diverging air currents with the trade winds blowing towards the equator and the westerlies towards the poles. For this reason no cyclonic rain can occur. Cyclones develop and give rain only in areas of converging air masses.

(*c*) they are too near the equator, to be affected by the equatorward advance of the temperate belt of cyclonic rain in winter.

(*d*) they are too far from the equator to be affected by doldrum convection rainfall belt when it advances poleward in summer.

(*e*) being on the western margins of great landmasses they are too far from eastern coasts to be affected by onshore winds, and the prevailing winds in the areas themselves are offshore or blowing from cooler to warmer areas, thus bringing no rain.

(*f*) the regions are bordered by cool ocean currents, the effect of which is to intensify the aridity of the coastal areas.

There are extremes of temperature both between summer and winter and day and night. The temperature may go up to more than 100°F during the day and down to and below freezing point during the night. The seasonal range, is between 25° to 35° the July and January averages at Aswan being 95° and 61° respectively, giving a range of 34°F. These ranges are due to clear skies, low humidity, bare earth and also the seasonal variation of insolation. The diurnal ranges are still larger varying from 25° to 45°, and reaching 74° in Death Valley of California ! Thus wide seasonal as well as daily range of temperature is characteristic of these climates. Of course

these areas are the hottest on the earth and the highest ever temperature of 136·4°F has been recorded at Azozia, located about twenty-five miles south of Tripoli. Scanty rainfall is another characteristic of the region, averaging usually less than 5" annually. At Calto it is only 1·2." Years may pass without rain and then one short burst may give enough rains to given an average of one or two inches for the rainless years. The rainfall variability in the region is the greatest in the world. Relative humidity is low, being about 45% in winter and 30% in summers. The figure may fall as low as 15% on a hot summer day. Clear skies are the rule and cloudiness varies from 1/10 in winter to 1/30 in summers.

The afternoons and evenings are marked by dust storms blowing with terrific speed and with scorching heat. The nights are calm but with shivering cold, particularly in the later part. These storms are known as 'Gibli' or Simoon in the Saharas.

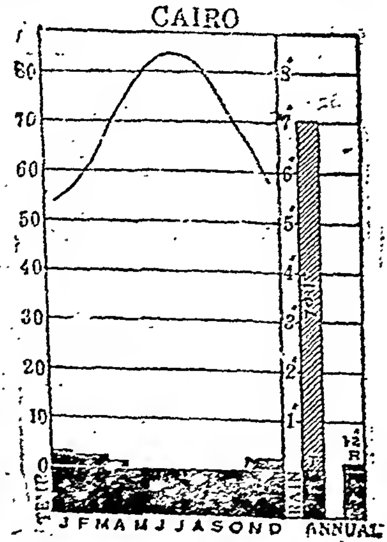



Fig 70

The following climatic data for Cairo are representative of this climate :—

| | J | F | M | A | M | J | J | A | S | O | N | D | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T. (F.) | 54·1 | 56·8 | 62·4 | 70·2 | 76·8 | 81·9 | 83·5 | 82·6 | 78·1 | 71·4 | 65·1 | 57·9 | 70·1 |
| R. (") | 0·3 | 0·2 | 0·2 | 0·1 | 0 | 0 | 0 | 0 | 0 | 0 | 0·2 | 0·2 | 1·2 |

(3) *Savana type.* Between the hot deserts, polewards and the equatorial belt of convectional rain, equatorwards is situated a climatic belt which is under the influence of the trade winds for one part of the year, and under the regime of the belt of convectional rains for the other. This area with alternating trade wind and doldrum influences is called the Savana type of climatic belt; and is characterised by a long dry season and a short season of rain. It is essentially a climate transitional between the equator and the Sahara type of climate and thus has some of the features of both, the Savanas are located above 5° to 15° North and South and the important regions belonging to this climate are the "Llanos" of the Orinico valley, the the "Campos" of Brazil, the Sudan and "Veld" of North and South Africa and the Australian "Downs".

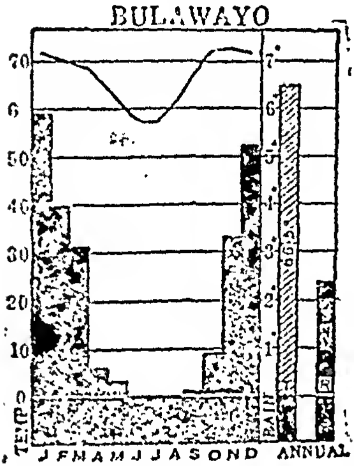



Fig. 71.

The region is hotter than the equatorial zone and temperature of hottest month may be 90° and the daily maxima may be 110°e Large diurnal ranges of 20° to 30° are a feature. There is somr seasonal difference in temperature, though not much. The winte temperature is about 78 to 80° F and the summer is about 85F The limits of the Savana depend on the rainfall, which varies from 60" on the equatorward limit to 15" on the desert boundary. The distribution of the rainfall is strictly seasonal, there being one wet and one dry season. The rainfall is concentrated in the summer months when the rain belt of the doldrums shifts poleward with the sun. Rainfall follows the sun. Rainfall is rather unreliable and the savanah type of climate is associated with rainfall failures and subsequent suffering. The relative humidity varies from 80% in the wet season to as low as 10% in the dry season. Throughout most of the year, dry and sunny days follow one another, and during these months strong but variable and dust-laden winds blowing from the deserts are common, *e.g.*, the Harmattan of the West Africa.

The following climatic data for Bulawayo, Rhodesia are representative of this climate:—

| | J | F | M | A | M | J | J | A | S | O | N | D | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T. (F.) | 71·5 | 70·2 | 68·9 | 66·0 | 61·2 | 57·4 | 57·2 | 61·2 | 67·6 | 72·4 | 72·5 | 71·8 | 66·5 |
| R. (") | 5·9 | 4·0 | 3·1 | 0·6 | 0·3 | 0 | 0 | 0 | 0 1 | 0·9 | 3·3 | 5·2 | 23·4 |

(4) *Monsoon type* is characterised by comparatively high temperatures throughout the year, and an alternation of a dry and a wet season. The seasonal range of temperature is considerable. The average temperature exceeds 80°F. for the most part of the region. The relative humidity of air is moderate except during the wet season.

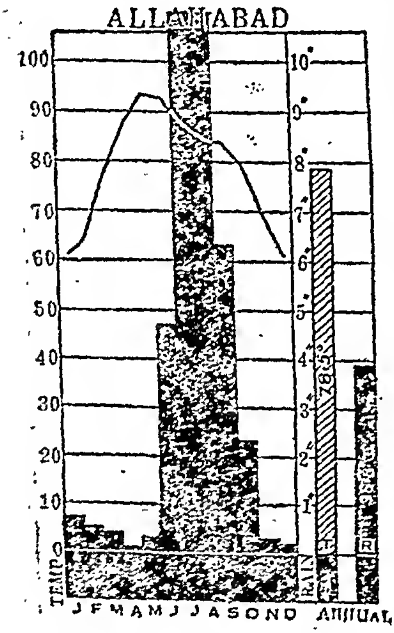



Fig. 72.

The distribution of rainfall is very uncertain, both in time and place. The rainy season lasts for about four months, June to September, with moderate to abundant precipitation. The rest of the year is quite or almost rainless. The pulling across the equator of the S. E. Trade winds under the name of the S. W. monsoons, highly saturated owing to their long passage over the sea, is a typical feature of the Indian monsoon region.

The monsoon type of climate is modified form of the Savana type owing to its greater rainfall and comparatively higher temperatures throughout the year. The monsoon types generally represent the oceanic types of the tropical climates.

The following climatic data for Allahabad are representative of this climate:—

| | J | F | M | A | M | J | J | A | S | O | N | D | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T. (F.) | 61·3 | 65·6 | 76·8 | 87·3 | 93·1 | 92·6 | 86·4 | 84·4 | 84 3 | 79·3 | 69·4 | 61·7 | 78·5 |
| Rain (") | 0·7 | 0·5 | 0·4 | 0·1 | 0·3 | 4·7 | 12·0 | 11 0 | 6·3 | 2·3 | 0·3 | 0·2 | 38·8 |

## Temperate Zone Climates

The temperate zone climates are not necessarily temperate. They are marked by even greater extremes than in the tropics. In the interior of the continents the winters are intensely cold, but the summers are very hot. On the western coasts, where the winds are westerly, highly equable conditions are found. On the eastern coasts of the continents the winds blow mainly off the land, especially in winter. These coasts have cold winters but cool summers.

The dominating control of the temperate zone climates is exercised by the ocean. The ocean currents and winds are the chief factors. The Gulf Stream and Kuro Shio among the warm currents and Labrador current and the Sakhalin current among the cold ones, exercise an important influence on the climates of countries which they skirt, particularly the coasts. Thus, the fiord ports of Norway remain open during winter owing to the influence of the Gulf drift long after the St. Lawrence has been closed with ice. The influence of these currents is carried into the interior by the prevailing winds.

Cyclones exercise an active influence in the climate of the temperate regions. They introduce an element of instability in the weather, and bring about 'spells' of cold or warm weather. The cyclonic activity is at its highest during autumn, though not confined to it. The temperate cyclones, ordinarily, are not as violent as those of the tropics. Examples of particularly violent storms in the temperate regions are to be found in the interior of the 'Tornadoes' which leave destruction in their trail. Their effect is, however, limited and is not as widespread as that of the typhoons in the tropics.

The types comprised within the temperate regions are :—

*In Warm Temperate Zone*: (1) Mediterranean, (2) Turan, and (3) China.

*In Cool Temperate Zone*: (4) West European, (5) Central European, (6) Prairie, and (7) St. Lawrence.

(1) *The Mediterranean type* is so called because of its extensive development around the Mediterranean Sea. It is characteristically a west marginal type of temperate lands, and is marked by a moderate range of temperature from season to season : though the daily range of temperature is considerable, varying from 15 to 30 or 40° F. Summers are hot and winters warm. The winter temperature is about 50° F. and the summer about 58° F. Light frosts may occur almost any night in the winter season, but killing frosts are rare. Note the significance of this feature for cultivation of fruits in the Mediterranean regions.)

Rainfall is moderate to scanty, in most places less than 30 inches annually. All or nearly all the rain falls in the winter season, generally in the form of short, heavy showers. Nonetheless, there are periods

when it may rain for hours or even for days. Lightning and thunder rarely accompany these downpours. In Chile, thunder causes as much terror as an earthquake; in South Africa, it is almost unknown; in California, it is rare.*

The most characteristic feature of the Mediterranean lands is the blue, sunny sky in winter and summer alike. Very few places outside the mountains have less than 2,000 hours a year of clear sunshine.

These climates are really the transition belt climates between the Trade Wind belt and the Westerlies belt. During winter, when the sun shifts to the south of the equator, the wind systems follow it. A certain part of the earth formerly under the Trade Winds is left over to the Westerlies which are blowing from the sea and are rain-bearing. These regions get their rainfall, therefore, in winter. During summer, when the whole system reverts to the north, the region is once more occupied by the Trade Winds which are dry, offshore winds. The summers are, therefore, dry.

A disturbing feature of this climate is the occurrence of wind storms. Hot winds originate in the deserts which adjoin several of the Mediterranean type areas. When these winds blow, the temperature rises well above the normal; the nights as well as the days are hot (often 85° F. at midnight). Although these storms may occur at any time of the year, spring and early summer is the season of greatest frequency. Different areas give different names to these winds, *viz.*, 'Sirocco' in Sicily and Italy and 'Santa Ana' in California. Some parts of the Mediterranean basin in Europe receive dry, cold winds from the north. These are called 'Mistral' in France and 'Bora' in Dalmatia. These are northerly winds and, therefore, their low temperatures are marked.

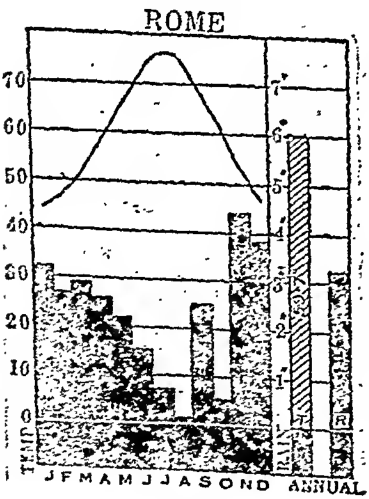



Fig. 73.

The following climatic data for Rome are representative of this climate:—

* Jones and Whittlesey, *Economic Geography*.

| | J | F | M | A | M | J | J | A | S | O | N | D | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T. (F.) | 44·6 | 46·8 | 50·9 | 56·7 | 64·4 | 70·9 | 76·1 | 75·6 | 69·6 | 61·7 | 52·7 | 46·4 | 59·7 |
| R. (″) | 3·2 | 2·7 | 2·9 | 2·6 | 2·2 | 1·5 | 0·7 | 1·0 | 2·5 | 5·0 | 4·4 | 3·8 | 32·5 |

(2) *The Turan type* of climate is an extreme climate. The annual range of temperature is wide. In the summer months, temperatures of more than 100° F. are not uncommon. In winter, there are periods when the temperature falls to (*minus*)—20° F. Moreover, the changes of weather are sudden. A fall of temperature amounting to 30° F. may occur within an hour. At Chicago a rise of 48° F. has been recorded in one day. The normal daily range of temperature, particularly in summer, is however, not large.

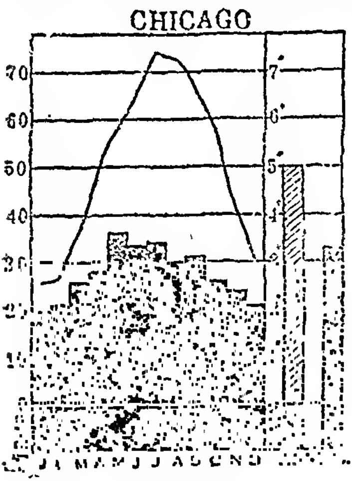



Fig. 74.

The annual rainfall is not heavy, but it is sufficient for agricultural purposes. More rain falls in summer than in winter, although the total amount differs a great deal from place to place. Most of the winter precipitation takes the form of snow, while some of the summer rain falls in prolonged drizzle and some in thunder showers.

The winds of the areas are extremely variable, both in direction and velocity. The humidity and cloudiness is not considerable. In some parts in Asia the humidity is less than 60 per cent.

The following climatic data for Chicago are representative of this climatic :—

| | J | F | M | A | M | J | J | A | S. | O | N | D | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T. (F.) | 25·6 | 27 0 | 36·1 | 47·4 | 58·4 | 68·1 | 74·0 | 72·9 | 66·3 | 54·8 | 41·5 | 30·3 | 50·2 |
| R. (″) | 2·0 | 2·1 | 2·6 | 2·8 | 3·6 | 3·3 | 3·4 | 3·0 | 3·1 | 2·6 | 2 4 | 2·1 | 33·0 |

(3) *The China Type* occurs on the eastern margins in the same latitudes in which the Mediterranean type occurs on the west. The

climate tends to be extreme. Sudden and decided changes of temperature are notably more frequent than in the Mediterranean type. Short periods of weather below freezing point ordinarily occur several times each winter. Light frost is also usual during winter. Summers are sultry, the temperature is often above 90° F. and the relative humidity of the atmosphere is high throughout the season. The daily range of temperature is moderate, being 13° F. for Hankow, and about 15° F for New York.

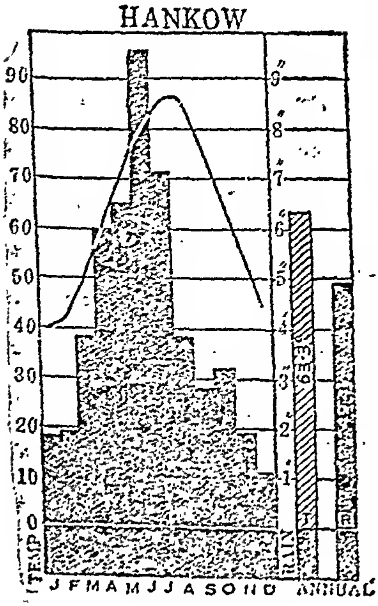


Fig. 75.

This climate is marked by abundant precipitation throughout the year. During winter, rainfall comes in drizzles which last for hours. Snowfall occurs every winter. The summer rain, however, falls in torrential thunder storms which are most frequent in the two months following the summer solstice in June. Very heavy showers occur and sometimes as much as 8″ of rainfall within one day. Hail sometimes accompanies these thundershowers and is more frequent in the interior lands than on the coasts. Autumn is the least rainy season.

All the regions of this type are subjected to occasional storms which are sometimes highly destructive. Hurricanes and typhoons often visit the coastal areas and work havoc. In the interiors, stormy winds like the 'Northern in U. S. A.' during winter, and 'Southerly Burster' in New South Wales during spring, with their violent, squally winds and low temperatures are typical.

The following climatic data for Hankow (China) are representative of this climate:—

| | J | F | M | A | M | J | J | A | S | O | N | D | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T. (F.) | 40·1 | 42·6 | 50·4 | 61·9 | 71·4 | 79·7 | 85·5 | 85·5 | 76·6 | 66·6 | 52·2 | 44·6 | 63·3 |
| R. (″) | 1·8 | 1·9 | 3·8 | 6·0 | 6 5 | 9·5 | 7·1 | 3·8 | 2 8 | 3·2 | 1·9 | 1·1 | 49·4 |

(4) *The West European type* is characterised by a mild winter and a mild summer. Snow falls occasionally for a month or two of winter, but seldom remains long on the ground. In addition to the slight seasonal variation, the daily range of temperature is very small in winter and only moderate in summer. For Kew (London) the daily range for January is 8° F. and for July 16° F. only.

The West European type is one of the rainier climates of the earth. Rainfall varies from 20 to 200 inches, decreasing from west to east. Nearly all the precipitation comes in the form of gentle drizzle; and about three-fourths of it comes in winter. Summer is the least rainy season. During the wetter season, cloudiness is prevalent, being about 80% for Lerwick in Great Britain. Winters are cold and damp, and fog is common along the coasts from which it is taken into the interior by the winds.

Autumn months are characterised by cyclonic storms which introduce a great deal of instability into the weather. Depressions are constantly appearing over the Atlantic Ocean and travelling in an easterly or north-easterly direction. Their paths may lie along any latitude between 30° and 70°, but the great majority are found north of 50° N. The depressions (cyclone), move forward anti-clockwise in the northern hemisphere. On the southern side of a cyclone the winds are westerly, while in front the winds are more southerly, the air is warm and muggy, the sky is cloudy, and rain falls. As the depression passes away to the east, the winds become more northerly and colder, the sky becomes clearer, and weather improves.

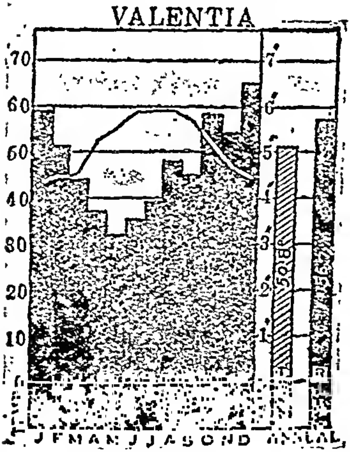



Fig. 76.

As the winds blow from the sea, the humidity of air is considerable at all seasons.

The lands of this type, particularly Great Britain, are not favoured in the matter of sunshine. The summit of Ben Nevis has the distinction of having the lowest average of sunshine in the whole of Europe, just under two hours a day. During winter, some places get much smaller amounts of sunshine or not at all. In December the city of London averages 15 minutes of pale sunshine a day compared with 100 minutes at Oxford.

The following climatic data for Valentia (Ireland) are representative of this climate :—

| Months | J | F | M | A | M | J | J | A | S | O | N | D | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp. (F) | 44·7 | 44·8 | 45·1 | 48·1 | 52·4 | 55·6 | 58·9 | 59·2 | 56·4 | 51·7 | 47·5 | 45·4 | 50·8 |
| Rain (″) | 5 9 | 5·1 | 4·4 | 3·7 | 3·2 | 3·5 | 3·9 | 4·8 | 4·5 | 5·8 | 5·4 | 5·6 | 56·7 |

(5) *The Central European type* is intermediate between the West European type and the Prairie type, partaking of some of the characteristics of both. The chief feature is the diminution of the oceanic influences. The summers are warmer than those of the West

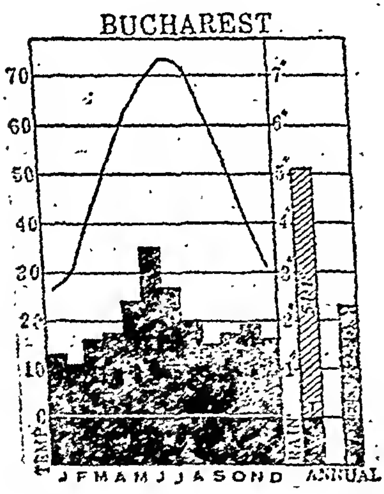



Fig. 77.

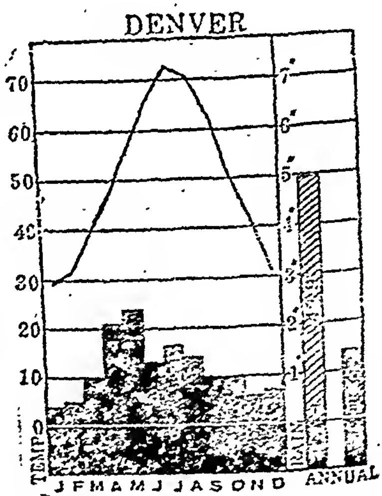



Fig. 78.

European type, but the winters are distinctly colder. The temperature conditions tend to be extreme, but not so extreme as in the Prairie type. Rain falls at all seasons but there is a distinct summer maximum, snow falls usually during winter ; the number of days on which snow falls in Berlin is 34.

The following climatic data for Bucharest (Rumania) are representative of this climate :—

| | J | F | M | A | M | J | J | A | S | O | N | D | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T. (F.) | 26·2 | 30 6 | 41·0 | 52·2 | 62·2 | 68·9 | 72·9 | 72·0 | 63·5 | 52·9 | 39·7 | 30·9 | 51·1 |
| Rain ('') | 1·3 | 1·1 | 1·6 | 1·7 | 2·4 | 3·5 | 2·7 | 2 0 | 1·5 | 1·7 | 1·9 | 1·6 | 23·0 |

(6) *The Prairie type* is a typical continental type of climate and is marked by great extremes. In winter, cold waves may sometimes reduce the temperature to (*minus*)—40° F. in many places, while in summer the temperature may go up to 100° F.

The precipitation is distributed throughout the year with the maximum in summer, particularly in the early summer. Nearly all the precipitation in winter takes the form of snow.

The following climatic data for Denver (Fig. 78) in U. S. A. are representative of this climate :—

| | J | F | M | A | M | J | J | A | S | O | N | D | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T. (F.) | 29·9 | 31·6 | 38·9 | 47·4 | 56·7 | 67·2 | 72·2 | 70·9 | 62·4 | 50·5 | 39·2 | 31·6 | 49·9 |
| R. ('') | 0 4 | 0·5 | 1·0 | 2·1 | 2·4 | 1·3 | 1·6 | 1·4 | 1·0 | 1·0 | 0 6 | 0·7 | 14·0 |

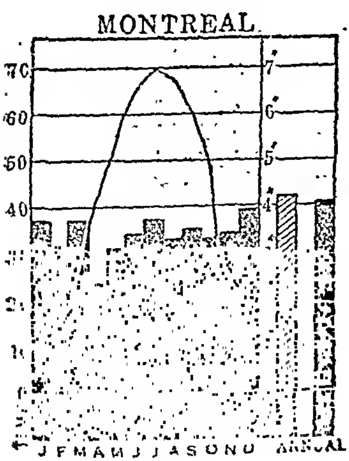


Fig. 79.

*The St. Lawrence type* is a modification of the Continental Prairie type due to the proximity of the sea. The seasonal range of temperature is slightly less than in the Prairies. The winters are almost as cold, but the summers are less hot, January temperature is about 13° F., while the July temperature is about 70° F.

Rainfall is considerably higher than in the Prairie type. Winters are marked by heavy snowfall. Cloudiness is common at all seasons. Weather changes are frequent. When the easterly winds blow, they bring damp air from the sea causing winters to be chilly, but summers are cool.

The following climatic data for Montreal (Canada) are representative of this climate :—

| | J | F | M | A | M | J | | A | S | O | N | D | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T. (F.) | 13·0 | 14·7 | 25·4 | 41·1 | 55·1 | 64·7 | 69·3 | 67 0 | 58·7 | 46·7 | 32 7 | ,9·1 | 42·3 |
| R. (") | 3·7 | 3·2 | 3·7 | 2·4 | | 3·4 | 3·7 | 3·7 | 3·5 | 3·5 | 3·4 | 3·7 | 40·4 |

## Polar climates

The polar types of climate are :—(1) The Northern Forest, (2) The Tundra.

(1) *The Northern Forest type* occurs in the northern hemisphere only. The winters are long and severe and summers short and warm. Summer days are very long and nights correspondingly short. The days are warm and midsummer afternoons may be as hot as those in the continental types of the temperate zone. Conditions are reversed in winter, which is very cold. Verkhoyansk (Siberia) holds the world's record for extreme cold, with (*minus*)—94° F. In a number of places in the north-central Siberia the average annual range of temperature is 120° F. This type of climate experiences a wider seasonal range of tempera ture than any other on earth.

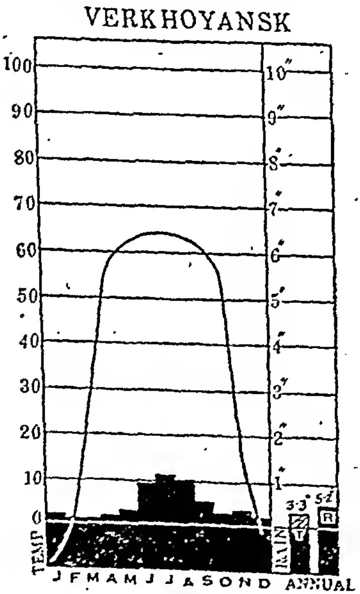



Fig. 80.

Precipitation is as scanty as that of the desert regions of the topics. Evaporation, however, is low and the light precipitation suffices for plant growth. Most of the rain comes in summer.

The following climatic data for Verkhoyansk (Siberia are representative of this climate :—

| | J | F | M | A | M | J | J | A | S | O | N | D | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T. (F.) | 58·2 | 48·1 | 23·8 | 9·5 | 36·3 | 56·1 | 59·9 | 51·6 | 36·1 | 5·7 | 34·1 | 51·3 | 3·3 |
| Precipitation." | 0·2 | 0·1 | 0·1 | 0·2 | 0·3 | 0·9 | 1·1 | 1·0 | 0·5 | 0·3 | 0·2 | 0·2 | 5·2 |

(2) *The Tundra type* has so long winters and so short summers that one season's snow is hardly melted before the fall of the next winter begins. During winter months low-hanging dull clouds completely obscure the sun. In summer, as in winter, cloudy and cold weather is conspicuous. Sharp changes in weather are the rule in summer.

## Classifications of climate

There is a considerable variety of climates on the surface of the globe, and therefore classifications of this endless variety are necessary for scientific investigation. Classifications of climate, as Miller points out, are of two kinds, (a) those based on a genetic relationship, *i.e.*, those which group climates together on the basis of similar causes, and (b) those based on convenience, *i.e.*, those which group climates together on the basis of similar effects. An ideal classification is one which attempts to combine both these bases.

## Mountain climates

*The Mountain Climates* in all the above regions are distinct from the general type owing to their height. The pressure of air decreases upward, and there is a loss of 1°F. of heat for every 300 ft. of elevation. The conditions of rainfall are determined by the direction ; the windward slopes being rainier than the leeward slopes where the Foehn effect warms the winds which are descending. The effects of these warm winds are particularly important in western Canada where they thaw the land earlier than normal for agricultural purposes.

## Continental and Oceanic climates

All the climates are sometimes grouped under the headings of 'Continental' or land 'Oceanic' according as they are dominated by land influences or by oceanic influences. The continental climates occur in the interior of continents where the oceanic influences have weakened.

## New classification of climate

A new classification of the world's climate, based upon the fixing of climatic boundaries by quantitative values of the various weather elements, has been developed by Dr. Koeppen.* The particular value of the Koeppen system lies in the fact that it uses numerical values for defining the boundaries of climate types. The Koeppen system has been widely adopted in most of the countries of the world.

* Wladimir Koeppen : *Grundriss der Klimakunde*.

Koeppen recognises five major divisions of the world's climates. These are identified by capital letters. These major divisions are as follows :—

A. rainy climates with no winters; the temperature of the coolest month being over 64·4° F.

B. dry climates; where evaporation exceeds precipitation.

C. rainy climates with mild winters; the coldest month having a temperature between 64·4° F. and 26·6° F.

D. rainy climates with severe winters; the temperature of the coldest month being under 26·6° F. and of the warmest month being over 50° F.

E. polar climates with no warm seasons; the temperature of the warmest month being under 50° F.

Each of these major divisions is then sub-divided into a number of categories. These categories are indicated by another capital letter, being added to the letter representing the major division. For example, BS and BW represent the two categories, semi-arid and arid, of B or dry climates.

Still further sub-division is made on the basis of some special feature of the climate. These further sub-divisions are represented by small letters added to the capital letters representing the major division or its categories. For example, Af means that the climate belongs to the A division mentioned above and that the rainfall of the driest month is at least 2·4 inches.

The distinction between the Tropical, Temperate and the Polar climates is characterised by the following features :—

1. Tropical Climates—Heat, Rainy season variation is the basis of the sub-divisions of the tropical climates.
2. Temperate Climates—Presence of a distinct summer and a winter season. Oceanic influence and frost are the basis of sub-divisions.
3. Polar Climates—Snowfall dominates. Growth of vegetation in summer is the basis of sub-division.

Another quantitative system is that developed by C. Thornthwaite which has not received the same recognition as the Koeppen system.

## Climatic changes

Rubner has divided the climates of Europe, including the mountain climates, into zones on the basis of the number of warm days. A warm day is defined by him as a day with mean temperature

above 50 F. No tropical zones are included in this classification. The zones are given below :—

| | Zone | No. of warm days |
|---|---|---|
| 1. | Sub-Arctic | 1—60 |
| 2. | Cool | 61—120 |
| 3. | Temperate | 121—180 |
| 4. | Warm Temperate | 181—240 |
| 5. | Warm | 241—300 |

Further study of the relationships between plant growth and mean monthly or mean daily temperatures by Koeppen and many others has led to further knowledge of the significance of certain limiting temperature values in the growth and distribution of plants. It has been found that many tropical plants do not thrive when the mean temperature of any month falls below 64° F. (18 C.), and that frosts do not occur when the monthly means are above 64°F. Hence, Tropical regions are limited by the requirement that the ormal temperature of all months be above 64°F.

The isotherm of 50° F. for the warmest month corresponds fairly well with the poleward limit of trees and the more hardy food crops. They require at least one month with the mean temperature above 50° F. to thrive and mature. Hence, months above 50 F. are spoken of as warm months. But most plants of middle and higher latitudes begin growth in spring when the mean daily temperature reaches 43°F. Their growth ceases in autumn when the daily mean temperature falls below it. The potential growth period in a given locality is, accordingly, that period when the normal daily temperature is 43 F. or more, and the regions in which the mean temperatures are continuously above 43° F. are regions of continuous growth.

For these reasons the average temperatures of about 64, 50 and 43° F. are natural limiting values in relation to plant growth, and therefore, in the division of the earth into climatic regions.

The isotherm of 32° F. is another such limiting value, because at that temperature the soil becomes frozen and the movement of soil moisture is stopped.

Rainfall also provides an important basis for climatic division. A simple subdivision on that basis is given below :—

| Division | Rain. Type | Rain. Amount inches. |
|---|---|---|
| Arid | Scanty | 0—10 |
| Semi-arid | Light | 10—20 |
| Subhumid | Moderate | 20—40 |
| Humid | Heavy | 40—80 |
| Very Wet | Very Heavy . | Above 80 |

The types of natural vegetation have also been used for climatic classification. The following gives a rough classification of this type :—

| Division | Vegetation | Mean Annual Temp. F. |
|---|---|---|
| Tropical | Palms, bananas | 78—82 F. |
| Subtropical | Fig, myrtles | 68—78 F. |
| Warm | Broadleaf Evergreen | 60—68 F. |
| Moderate | Deciduous trees | 48—60 F. |
| Cold | Coniferous trees | 40—48 F. |
| Polar | Dwarf shrub or mosses. | Below 40 F. |

As temperature and rainfall vary continuously between large limits the division into types is more or less arbitrary, and can be continued indefinitely as smaller and smaller differences are considered. The consideration of these smaller differences is known as 'Microclimatology.'

## Climatic Changes

The geologists and the botanists have been able to find indisputable evidence of great variations in climate in the past. The most conclusive proof of climatic changes are offered by ice ages. Today only small areas of the world are covered with ice. But proofs have been found that once ice covered large areas of the globe. This is concluded from the fact that great masses of glacial drift cover Eastern Britain and Northern Europe and America. Further there exists glaciated topography in large areas where no ice exists today, *e.g.*, the Great Lakes of North America have a glacial origin. One of the oldest known sedimentary rocks is glacial in origin, which indicates the presence of an ice sheet. This is a boulder clay, discovered by Prof. Coleman in Canada. It extends for about 1000 miles in an east-west direction across northern Ontario from the northern shore of lake Huron. At first it was thought that there was only one ice age, when about a fifth of the world's land surface was covered with ice. But in 1859, evidence in Northern India, and later discoveries in America and Africa proved that there have been cycles of glaciation in earth history.

A second evidence of climatic changes is provided by coal measures. Coal is produced from dense vegetation growing under subtropical climate, and many of the world's greatest coalfields are found in temperate climates, *e.g.*, Great Britain, Ruhr, Spitzbergen. This fact proves that climate must have changed.

A third evidence of climatic changes is supplied by fossils. During the ice ages the fossils of animals living in cold climates are sound in subtropical regions, while during the interglacial periods fossils of such tropical animals as the hippo are found in England. Coral reefs exist in rocks of different ages in Great Britain, which is too cold for corals today.

The geological record provided by rocks and the biological record provided by fossils seem to indicate the existence of two climatic cycles. The minor cycle recurs every 200,000 years or thereabout and has determined the duration of the four Pleistocene ice ages and also the development and migrations of the four main races of man.

The major cycle is about 100,000,000 years long, and there is a record of three such major cycles since the beginning of the Cambrian age.

The minor cycles are superimposed on the major cycles in such a way that in each major cycle, after long ages of fairly uniform climate on the whole earth, there develops a zonal arrangement of climates. This culminates at the four great ice epochs, *i.e.*, in the late Proterozoic, Devonian, Permian and the late Tertiary times.*

Beginning with the Pleistocene we get the extraordinary changes in the climate shown by the four ice ages and the three interglacial ages (when the climate warms a little). It is in the Miocene, however, that the zonal type of climate begins to predominate. It continues from that period to the present. It is, therefore, in the early Tertiary that we begin to see the premonitions of the coming glacial periods. These premonitions are provided by a series of fluctuations which gradually increase in intensity.

Apart from these changes that took place in the geological times, there are evidences also of changes in the historical times. The most interesting evidence is that of 'Big Trees' described by

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*The following names are given by the geologists to the divisions of the earth's history from the earliest to the recent times :—

| *Era* | *Periods Under Each Era.* | |
|---|---|---|
| Archaeozoic | Little known oldest division. | |
| Proterozoic | " " | |
| Palaeozoic | Cambrian | |
| | Ordovician | |
| | Silurian | |
| | Devonian | |
| | Permian | |
| Mesozoic | Triassic | |
| | Jurassic | |
| | Cretaceous | |
| Cenozoic | Eocene | Tertiary. |
| | Oligocene | Tertiary. |
| | Miocene | Tertiary. |
| | Pliocene | Tertiary. |
| | Pleistocene | Quaternary |
| | Recent | Quaternary |

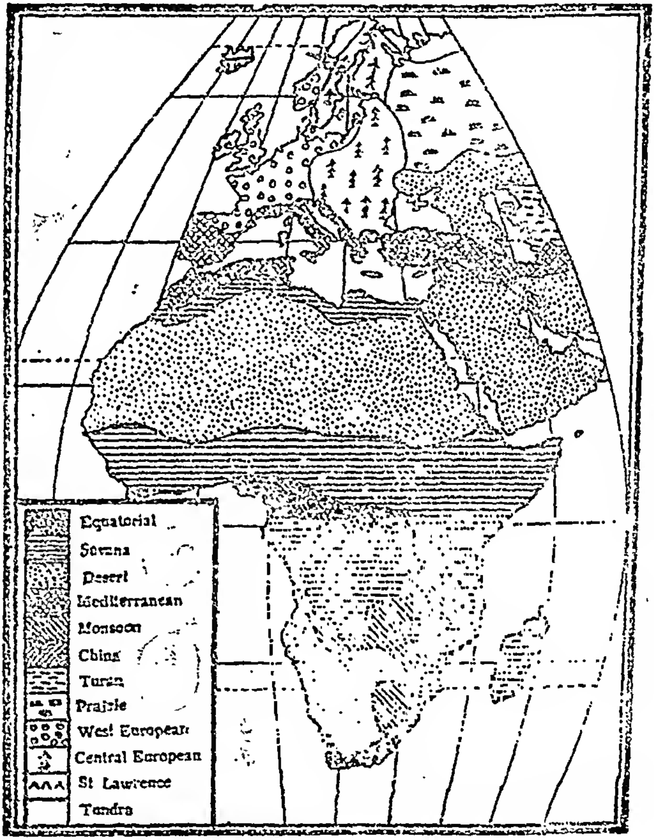
Huntington.* These big trees are the Sequoia trees growing in California, in North America. They live for several thousand years. The amount of rainfall is the chief factor in their growth, which expresses itself in the breadth of annual rings marked on the stump of the tree. These rings have been measured when the tree has been cut down. Judging from the relationship between the rings on the Sequoia and the rainfall today some of the trees show that they have


[Modified from Koeppen

Fig. 81. Climatic Types.

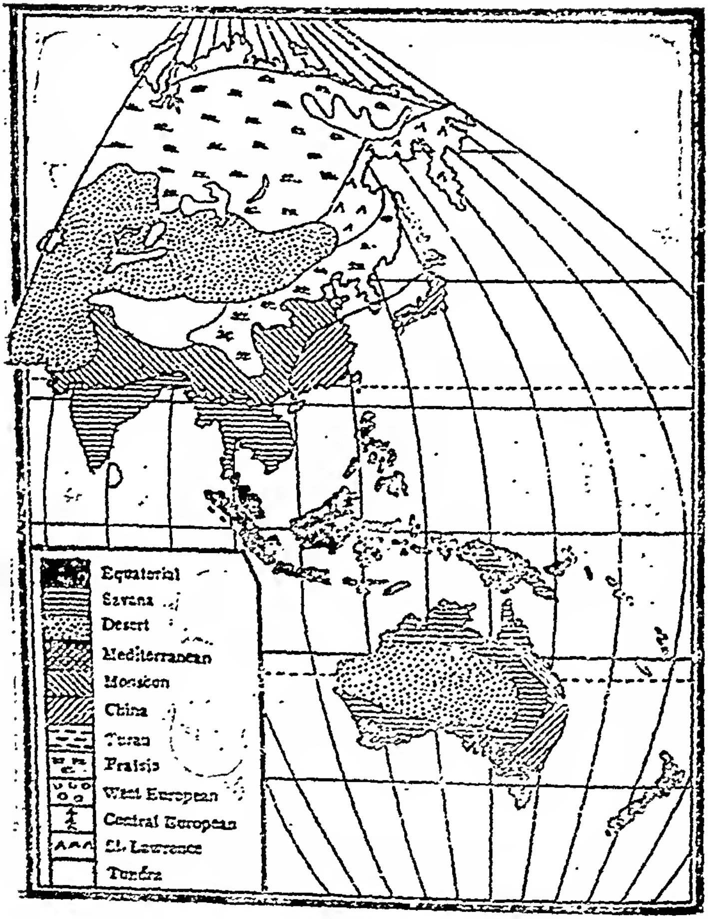
*E. Huntington, *Climatic Changes.*

lived for at least four thousand years. They also reveal considerable changes in climate during their life, *e.g.*, over the greater part of the temperate regions of the northern hemisphere there was heavy rainfall between 1800 B. C. and 500 A. D. The evidence of these trees also shows that the rainfall was generally light until about 1000 A. D., when it showed a sharp rise.




[*Modified from Koeppen*

Fig. 82. Climatic Types.




[*Modified from Koeppen*

Fig. 83. Climatic Types.

Another class of evidence is from the ruins found in the desert regions of today. The largest ruins of this type invariably lie near the main drainage lines showing thereby that at one time water must have been present permanently in those streams to enable those villages and cities, now in ruins, to arise on their banks.

Conclusive evidence of historical climatic changes are afforded by actual records of temperature and rainfall. A large number of cycles based on this data have been discovered. Shaw tabulated 130 cycles ranging up to 260 years.

## Causes of climatic fluctuations

Anders Angstrom (Geografiska Annaler, vol. 17, 1935) classifies the factors that may produce widespread simultaneous climatic fluctuations as follows :—

1. Changes in the amount of solar energy reaching the earth, resulting from variations in (a) amount of radiation reaching the upper surface of the atmosphere (*i. e.*, the solar constant), (b) transmission of radiation by the clear atmosphere and (c) mean cloudiness.

2. Changes in the atmospheric circulation.

3. Changes dependent on phenomena whose influence on weather is still obscure, such as corpuscular radiation from the sun and number of nuclei of condensation.

4. Other theories explaining changes in climate are (a) the theory of continental drift, (b) the theory that the angular inclination of the earth's axis is varying.

## Effect of climate on man

Man cannot make his own climate. He must, therefore, adapt his life and his outlook to the climate that nature makes for him. If he is to succeed in his activities, he *must* co-operate with nature in this one field at least. His clothing must be such as will give him the necessary protection against the weather elements ; his shelter must be able to withstand against the onslaughts that may be made not only by his enemies, but also by climate. His food, his habits and his movements will all be affected by climate. For example, in the tropical climate, a man may rise early in the morning and may go out of doors without putting on any clothes, but he cannot do this in the cold climate of the north. He will be frozen to death if he dares out of doors without proper clothing and feeding in Russia early on a winter morning. It is no surprise, therefore, that we find so few, among the Europeans, living in India being early-risers. During winter, in Russia, the roads and railway tracks are covered with heavy snow and traffic on them is possible only after the snow has been removed. Sometimes even petrol freezes in the engines of the motor cars! The flooded rivers of the tropical regions create similar difficulties in movement due to climate.

Man's food is drawn, directly or indirectly from the vegetable kingdom. The meat-eating people get their food from cattle or sheep which thrive on vegetation. The vegetarians get their food directly from plants. Even the fish which provide so much food to man depends ultimately on a form of vegetable growth, the plankton.

The growth of vegetation is controlled by climate. Temperature, rainfall and sunshine are elementary requirements for its growth.

Man can draw upon only particular types of vegetation for his food. These are generally grasses ; though certain trees—fruit and beverage trees like mango, apple, lemon, cocoa, coffee, walnut—are also useful in this respect. Special types of vegetation require special types of climate and soil. It must be noted here that soil itself is a product of climate. The introduction of cultivated crops to supply man's food and other requirements mark a stage in the development of man which is made possible only through co-operation with climatic laws. Wheat, for example, requires a particular type of temperature and a certain amount of rainfall for its successful growth. Man, therefore, selects the best season when such temperature and rainfall are provided by nature. No doubt, it can be argued that the modern man can provide these climatic requirements by artificial means, but he can do that only in the laboratory not in the open fields. His dependence on climate for the cultivation of wheat, or any other cultivated crop for that matter, is fundamental.

In one respect man has been able to provide artificially a climatic requirement of agricultural crops, and that is in respect of water. Man is able to provide water to cultivated crops in certain areas by artificial irrigation. But even here he is not entirely independent of climate. For the supply of water that he transfers from a river to a canal and then to the field depends upon rainfall or snowfall. Many a canal will be dry, if rain were to fail.

In extending agriculture on the earth's surface, man must, therefore, take help from climate.

The influence of climate on industry is not less important. Certain raw materials of industry are dependent directly on climate. Raw wool is supplied from sheep who must graze on grass. The growth of grass, as has been noticed above, depends directly upon climate. Climate thus determines the quantity of raw wool through the quantity of grass available for the sheep. It also determines the quality of raw wool. In colder climates, the sheep grow finer wool than in warm climates. In order to protect the sheep from cold, nature provides longer and finer wool on sheep skin than is necessary in hot countries. The dependence on climate of raw materials derived from agriculture is obvious.

There are certain raw materials whose supplies have been due to past climates. The vast salt deposits of Alsace in Germany or Cheshire in England were made possible by the past geological climates. The vast beds of coal which move the wheels of modern industry are the outcome of such a climate. Coal is the metamorphosed form of a luxurious type of vegetation which grew under the climate prevailing in certain areas in the geological past. In the absence of that type of climate and, therefore, that vegetation, there would have been no coal on the earth today. The develop-

ment of Hydro-electricity is, similarly made possible by climate. Rainfall or snowfall which provide the running stream which is harnessed for electricity depend directly on the present climate. Hydro-electricity is developed most easily in areas which have a glaciated topography. This glacial topography is the outcome of a past climate, when over certain parts of the earth it was so cold that thick sheets of ice were found there. The change in the climate caused a melting of that ice which, during the course of its retreat, left this glacial topography.

It was mentioned in the Introduction to this book that climate provides man with the necessary impulse for activity. It is through this activity that he gathers experience and becomes civilised. The development of human character—which is another name for accumulated experience—and human civilisation leading to the world's material development, are themselves dependent upon climate.

Most of the population of the world today is found in the plains where the present climate makes possible the production of large quantities of food for the support of this population. China, India, Japan, and the south-eastern parts of Asia support roughly about one-half of the total population of the world. Other centres of large populations are to be found in industrial Europe and North America where, owing to the effects of the past climates, there are large deposits of coal, iron or other factors favouring the localisation of manufacturing industries.

On the other hand, there are the vast stretches of the Sahara, Arabia, Australia, and other deserts where very few people live today. Neither the present, nor seemingly the past climate, has been helpful to attract large populations to these areas. Want of water is the greatest drawback to human settlement in these deserts. Similarly, there are the cold polar deserts. The Antarctica is as big as the continent of Europe, yet not a single human being has settled there. The climate is too cold there.

In the Congo and the Amazon Basins, and in other equatorial regions, the climate favours the growth of dense forests. These dense forests and the hot, moist climate which gives rise to them, repel settled populations.

We find, therefore, that the distribution of population on the earth's surface today is determined by the present or the past climate.

Whenever there have been changes in the climate of an area so as to affect adversely the production of food, migrations of people on a large scale to more favourable adjoining areas have taken place. Such migrations from Central Asia in the past have brought about political changes in Europe and Asia of far-reaching importance.

According to Semple,* the great exodus and displacement of people from western Asia due to desiccation about 2,000 years ago contributed to the downfall of Rome and peopling of the agricultural lands of Central Europe. The invasions and occupation of China, India and the valleys of the Tigris-Euphrates and the Nile were all due to this. This theory of desiccation has been supported by other people like Huntington, the American geographer, Prince Kropotkin, a Russian geographer and several others. Thus, climate has been the indirect cause of some of the most important development in the world's history also.

Not only in the historical, but also in the geological past, climate has been the cause of migrations of populations. In the recent geological times, a vast continental glacier spread southward and covered half of Europe. The ice front reached far south into Germany and Central Russia. The men who lived in Northern Europe at that time were forced, therefore, to move southward by the advancing glacial ice. According to Griffith Taylor the last four ice ages are connected with the four great migrations of man. The last ice age thrust out the early Aryan races (of olive colour) not only to India, Europe and Africa, but also into north China and Japan. A number of migrants reached America and are to be traced in the tribes of Brazil. The differences in colour of races are also, according to Taylor, connected with the climatic changes that took place in the great Asiatic breeding place, the Aralo-Persian region. The hot moist climate produced red-brown races; the cool moist regions produced olive-brown races; the arid warm regions produced yellow races. These races darken or tan if they live long in a hot region, and bleach if they live long in a cold moist region.

Climate is, therefore, the most fundamental factor in the development of man on the face of the earth.

CHAPTER X.

# FACE OF THE EARTH

PROPORTION OF LAND AND WATER—EVOLUTIONARY CYCLE—EXOGENETIC FORCES—ENDOGENETIC FORCES—ROCKS—IGNEOUS ROCKS—SEDIMENTARY ROCKS—METAMORPHIC ROCKS—WEATHERING OF ROCKS—INFLUENCE OF ROCKS ON LAND-FORMS—LANDFORMS—CONSTRUCTIONAL—DEPOSITIONAL—INFLUENCE OF CLIMATE ON LANDFORMS.

## Lithosphere

The face of the earth is covered by land, water and various forms of life. From man's point of view it is the land or the lithosphere that is the most important feature of the earth's face. For it is on the lithosphere that man builds his home and finds or creates conditions favourable for his material development. Not only man, but all other forms of life on the earth are 'based' on the lithosphere. Even the marine life that lives in water depends for its existence on the fresh water and the fine silt coming from the lithosphere. It is for this reason that most of the marine life in the sea follows closely the boundary between land and sea. Birds which fly most of the time in the air have to get their perch on trees that have their roots buried into land. Lithosphere, therefore, has the greatest significance in the study of geography.

The earth's surface covers roughly about 197 million square miles in area. Of this lithosphere covers only about 50 million square miles, or just a little more than one-fourth (29%) of the total area. The following diagram shows that the distribution of land and water is not uniform over the earth. This small area of the land surface compared with its great importance for all forms of life on the face of the earth increases our interest in land sufaces.

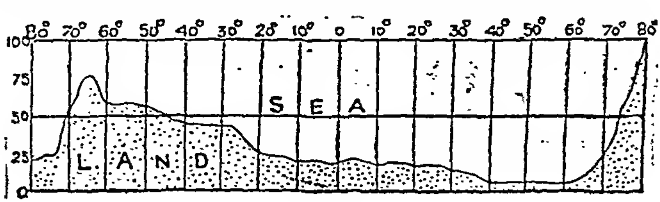



Fig. 84

Proportion of land and sea in different latitudes. It will be seen from this diagram that land predominates between 20° and 70° in the northern hemisphere and between 70° and 80° in the southern hemisphere.

The original face of the earth must have resulted from cooling of a gaseous mass, if we believe in any of the hypotheses discussed in Chapter I above. This cooling must have produced wrinkles on the face of the earth. So that the original surface of the earth must have been marked by elevations and depressions existing side by side.

The face of the earth wears a veil. This veil is the atmosphere. Unlike the thin veil of muslin that covers the face of a maiden, the atmospheric veil of the earths' face is always busy transforming it (the earth's face). The heat, moisture and the chemical forces present in the atmosphere are the active forces of this transformation of the earth's face). And as the atmosphere is never steady, it follows that the appearance of the earth's face is not always the same. It is constantly changing. Like the beauty experts of Europe or America today, the atmosphere is busy smoothing down the wrinkles found on the face of the Mother Earth. Elevations are, therefore, gradually disappearing in filling up depressions. But the Mother Earth is old, very old indeed ! The beauty treatment that it receives from the atmosphere does not seem to be a complete success. For new wrinkles are appearing where, apparently, there were none before. The wrinkled appearance of the face of the earth, therefore, still persists. Unlike our own beauty experts, however, the atmosphere does not give up ! It still persists in its efforts to transform the appearance of the earth's face !

## Evolutionary Cycle

The face of the earth has changed during the past and is changing during the present. Parodoxical as it may seem, the first suggestion that the face of the earth is changing came from the mountains, mountains which have been looked upon through all ages as the symbol of permanence ! We know from the geologists that the mountains are of different ages. We also know that frost and rain are continually wearing them away. Rivers wear away rocks hard as well as soft. The debris that they carry away in this way is deposited in the sea and forms material from which new rocks are built at a later date. The vast quantities of silt that are removed every year by the rivers coming down from the Himalayas must be reducing the heights of this giant, so that in times to come the Himalayas, like the present Arravallis or the Satpuras will be lowered to mere hills of low elevations.

It has been estimated in the United States that the rivers of that country rob it in this way of 783 million tons of its soil every year. The material so robbed, since the grant of independence in 1776, could be built up into a mountain, seven miles across at its base, rising to a height of 4,500 feet about the surrounding country.*

*A. E. Trueman, *This Strange World.*

The scientists prove that the rocks which form the present mountains must have been formed under the sea. From the fossils present in those rocks as well as the nature of the rock material, they can estimate the depth of the water under which these rocks lay and the distance that separated them from the coast. This is a clear evidence of the fact that the debris carried to the sea by the river water is not lost to use for all times, but comes back in the form of raised land or mountains. In short, what is broken away in one place must be built up again in another. Thus, the lithosphere is born under the sea.

The forces that bring about the rise of the rocks that have been formed out of the debris, carried to the sea by rivers, have their origin within the earth itself. These internal forces of the earth cause not only the slow rise of the land that lies buried under the sea; but also produce eruptions and fissures on the earth's face. These are the volcanic cones and the rift valleys that are found in every part of the earth's surface. Contemporary evidence is not lacking about the rise of land. It is known that the whole of Scandinavia is gradually tilting from north to south. It has been calculated that the northern portion is rising at the rate of about 4/10 of an inch every year, while the south-eastern part remains at the same level. Similar changes have been observed in Finland and Scotland also. Thus, there are two different types of forces that are active in changing the face of the earth :—(*a*) those that are due to the atmosphere and are, therefore, external to the earth, called generally *exo-genetic* by the geologists, and (*b*) those that have their origin in the interior of the earth and are described generally as *endo-genetic*.

The endo-genetic forces elevate rocks, while the exo-genetic forces level them down. There is a constant rivalry going on between these two forces, so that none of them seem to take any rest. Out of the incessant struggle between these two types of forces are born the various 'land forms' which have such a fundamental influence on the development of man. Lands are raised, they are eroded and out of the eroded material new lands are formed. This is the evolutionary cycle that holds the stage on the face of the earth.

## Rocks

The material out of which the earth's crust is formed may be described as rock. The rock is nothing but the aggregation of a certain number of minerals* which were present originally in the

*The most common minerals and their proportion in the composition of a common rock are:

| | | | |
|---|---|---|---|
| Silica | 50% | Alumina | 15% |
| Iron Oxides | 7% | Lime | 5% |
| Soda | 4% | Potash | 3% |

earth when it was in a molten or gaseous condition. The original rocks were formed by the cooling of molten matter and were, therefore, compact or massive. These original rocks were then subjected to erosion produced by the earth's atmosphere. The eroded material or the sediment was deposited in the sea and, in due course of time, was reconverted into rock. But this new rock differed from the original rock in that the material forming them lay in horizontal beds. Some of the rocks that were formed under the sea were built not from sediment received from the original rocks, but from the decayed organic matter derived from dead vegetation or dead insects. Thus, there came to be recognised two principal classes of ro ks :—(*a*) those that were formed from cooling of a molten matter ; called *igneous rocks* and (*b*) those that were formed under water from sediments or decayed organic matter, called *sedimentary rocks.* Some of the sedimentary rocks, on being subjected to considerable heat and pressure, became so altered that it became difficult to recognise them. They were placed in a separate class and were called (*c*) the *metamorphic ro ks.* The rocks constituting the earth's crust are, therefore, grouped according to the method of their formation, under the following :—

(*a*) Igneous rocks.

(*b*) sedimentary rocks, and

(*c*) metamorphic rock.

## Igneous Rocks

Igneous* rocks are rocks formed through the solidification of molten materials that originated within the earth. They are also called primary rocks. These rocks are massive as distinguished from stratified. They have been formed by cooling of a molten mass and are, therefore, crystalline and massive in structure. They are made up of interlocating mineral grains that cling together. The most common form of the molten matter on the earth being the molten magnia, these rocks are naturally associated with volcanic activity, being dominant in the neighbourhood of volcanoes, active or dormant.

One classification of igneous rocks is on the basis of mode of occurrence. When the magnia is poured out from the earth's interior to the surface, it is called lava. When volcanic activity starts some magnia is thrown up on the surface as lava, but a large part still remains inside the fissures below the surface of the earth. Igneous rocks, therefore, form from the cooling of the molten matter both inside the earth and on its surface. The lava on the

*Igneous rocks are also known as eruptive rocks. The word igneous has been derived from the Latin word *ignis*, meaning *fire*.

surface cools down quickly, while the intrusions of the molten matter inside the earth cool slowly. This divides the igneous rocks into two main classes :—(*i*) extrusive or plutonic rocks and (*ii*) intrusive or volcanic rocks. The extrusive rocks are those that form by cooling of the lava on the surface, while the intrusive rocks are those that form by cooling of the intrusions of the molten matter inside the earth. The intrusive rocks are later exposed on the surface when the surrounding material is removed by erosive action.

The rate of cooling of the two masses accounts for the essential difference between the above two classes of igneous rocks. Where the cooling is quick, as in the case of the lava on the surface, there is little or no time for the formation of crystals or large grains. In some cases the cooling of the lava was so rapid that there was no time at all for any crystals to form and in such cases a natural glass has been produced. But in the case of the intrusive rocks which solidified below the surface, there was more time for big crystals to grow. These crystals are of different minerals, generally quartz, feldspar and mica.

The most important example of the extrusive igneous rocks is *basalt* which is fine-grained, while *granite* is the important example of the intrusive igneous rocks.

Another classification is based on mineral composition. All igneous rocks contain 40 to 80% of silica. Those rocks which have more than 66% silica are known as acid igneous rocks; those with 66-52% silica are known as Meso-Silicic rocks; those with 52-40% silica are called basic igneous rocks and those with less than 40% silica are called as ultrabasic rocks. Granite is the example of an acid rock; while Basalt is the example of basic rocks. Acid rocks are generally pale-coloured and are resistant to weathering. The basic rocks, on the other hand, are dark-coloured, and weather easily. A third classification of igneous rocks is on basis of texture. By texture is meant the coarseness of grain of a rock. The slower the magmia is cooled, the larger the grain size. Those rocks in which the grains are large enough to be seen by the naked eye, *e. g.*, granite are called Phaneritic Rocks. Those in which the grains can be identified by a microscope are known as Aphantic Rocks. Thirdly those rocks in which there is little or no crystallization, belong to the Glassy rocks.

Igneous rocks are also called primary rocks because all other sedimentary and metamorphic rocks are ultimately derived from them. These rocks occur in India in the Peninsular region and here and there, in the Himalayas.

The Pyroclastic Rocks are a hybrid between sedimentary and igneous rocks, the arrangement being sedimentary and the material of volcanic origin. Volcanic Agglomerate is a mass of angular lava blocks while tuff is volcanic ash cemented into a soft rock.

## Sedimentary Rocks

Sedimentary* rocks are the most widely-spread rocks on the surface of the earth. It is estimated that they cover roughly about 75% of the surface of the earth, the remaining 25% being taken up by the igneous and the metamorphic rocks. Even though the sedimentary rocks are so *widespread* in area they form only a very small proportion of the earth's crust. They form only about 5% of the earth's crust, the remaining 95% of the crust being composed of igneous or metamorphic rocks.† In other words, the sedimentary rocks are important for extent, not for *depth* in the earth's crust.

Sedimentary rocks have been formed out of the sediments received from the previously existing rocks, which are igneous rocks in the first instance, and all kinds of rocks at a later stage. These sediments are deposited in the sea where they lie as horizontal beds. The deposition of the rock material is due primarily to a decrease in the speed of the transporting agent. During the course of this deposition, the particles are sorted out; the larger and the heavier particles are deposited first and then the smaller ones, down to the smallest particle. This assortment during the deposition of the rock material according to weight, and the trasporting power of the carrying agent results in *stratification* which is the most characteristic feature of the sedimentary rocks. On account of this stratification, these rocks are also called 'stratified rocks'.

Although built from the waste of existing rocks, and deposited originally in an unconsolidated state, the layers of sediment are consolidated by the deposit of mineral matter which cements together the individual grains. The formation of sedimentary rocks requires, therefore, not only the sediment or the rock material, but also the cementing material which is held in solution by the water in which the sediment is deposited, and is then precipitated.

A large number of insects living in the sea have hard shells which have been built up from the chemicals present in water. When these insects die, their remains are broken up by the action of waves and provide the material for sedimentary rocks. Similarly, certain organic matters provide carbon compounds which also form material for sedimentary rocks. Such is the vegetable matter from

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*From the Latin word 'Sedimentum' meaning settling down.

†For the outer 10 miles of the earth's crust, Clarke has estimated the rock composition to be about as follows:—

igneous : rocks 95 p. c.:
shales 4 p. c.
sandstones 0·75 p. c.;
Limestones, 0·25 p. c.
[U. S. Geol. Survey Bull. No. 695, 1920].

which coal is formed, or the animal matter from which petroleum is produced.

These three classes of material from which sedimentary rocks are formed are described :—

(*a*) Clastic or rock material,

(*b*) soluble chemical material, and

(*c*) carbonaceous or organic material.

Based upon the different types of material from which they are formed, the sedimentary rocks are divided into three broad classes ; clastic or fragmental (fragmental, because they are formed by fragments of rocks), chemical and organic. The following are the examples of the various classes :—

### Classification of Sedimentary Rocks

| CLASS | EXAMPLE |
|---|---|
| 1. Clastic | Gravel beds,<br>Conglomerates,<br>Sandstones,<br>Shale. |
| 2. Chemical | Stalactite, Oolite.<br>Iron deposits,<br>Salt,<br>Gypsum. |
| 3. Organic | Most Limestones,<br>Dolomite,<br>Coal. |

Sedimentary rocks are classified into Aqueous Rocks, (those formed under water) and Aeolian Rocks (those formed on land).

I. Aqueous rocks are further classified into

(A) Mechanical deposits, which have been formed by the physical deposition of material under water by rivers. Mechanical deposits are of two kinds, (*a*) siliceous or sandy, for example, sandstone, conglomerate, till and breecia, and (*b*) argillaceous, or clay ~~and~~ and mud, for example, shale, and more.

(B) Chemical precipitates Rocks of this group are of restricted extent and include gypsum, marine iron ore like the Cleveland deposits and rock salt.

(C) Organic accumulations formed out of bodies of organisms. The chief of these is limestone, peat, coal and chalk.

II. Aeolean Rocks are not very important. These include, drift sand rock or the consolidated sand of dunes, falus formations and loess.

There are numerous types of sedimentary rocks. Sandstone is made up of grains of sand, cemented together, usually by calcium carbonate or silica. Those cemented by calcium carbonate weather rapidity into sand while the silica cement is very durable. Sandstones cover 12% of all sedementary rocks. Gravel is a mass of rounded pebbles which when cemented together is called conglomerate. Breccia is a cemented mass of angular pebbles. Till is unstratified drift deposited by glaciers.

Shales which comprise 82% of all sedmentary rocks are formed of finely stratified clay, while mall is a clay containing much calcium carbonate. Chalk, limestone and dolomfites form about 6% of all sedimentary rocks and originate in organic accumulations.

There are certain characteristic features that are associated with sedimentary rocks. The most important of these features are :—

Stratification, marks of ripples or waves, mud cracks and fossils. It is by these features that the sedimentary rocks are often recognized.

## Metamorphic Rocks

Sometimes owing to heat pressure and chemical action to which the two main classes of rocks discussed above are subjected, a new class of rock is produced. This new rock is a complete metamorphosis of the old rock. This metamorphosis produces a new structural rock subjected to metamorphism.

As Longwell has aptly pointed out, rocks like men, adjust to their environment. "Metamorphism is the result of the tendency of rocks to adjust themselves to their environment." If the environment of a particular rock changes as regards pressure and temperature, then the rock tries to adjust itself to the changed environment and metamorphosis takes place.

Metamorphosis is of two types :—(*a*) regional or dynamic metamorphism and (*b*) contact or thermal metamorphism. The regional metamorphism is due to slow changes of pressure brought about by mountain building. Rocks are buried under folds and are subjected to huge pressure which generates heat and thus causes fundamental changes in structure and minerals of the buried rock. As mountain building spreads over large areas, regional metamorphism becomes widespread. Contact metamorphism, on the other hand, is due to contact of molten matter injected into existing rocks

due to volcanic activity. As contact metamorphism is local in character, its effect is limited in area. It is on this account that metamorphic rocks are generally confined to mountainous regions* either new or old : or in the neighbourhood of volcanoes.

Another more elaborate classification of metamorphism is into (*a*) static metamorphism, occurring near the surface, without stress and in the presence of water. (*b*) Dynamic metamorphism discussed above. (*c*) Igneous or pyro-metamorphism due to intruding magima and (*d*) hydrothermal metamorphism caused by ascending hot waters.

The metamorphic rocks form a very wide group, but the most important ones are given below :—

| ORIGINAL ROCK | METAMORPHIC ROCK |
|---|---|
| Sandstone | Quartzite |
| Clay | Slate |
| Limestone | Marble |
| Shale, fine-grained | Schist |
| Shale, coarse | Gneiss |
| Coal | Graphite |

Metamorphic rocks are divisible into, Foliated and Non-foliated. The foliated rocks are those which split up into flapes, chief foliated rocks are gneiss generated by violent compression of granite and schists. Non-foliated rocks signify a metamorphism less extreme than that which produced foliated rocks. Such are quartzite, slate, and marble.

Rocks once metamorphosed may undergo another metamorphosis. Rocks which have undergone two and more metamorphisms are called *polymetamorphic rocks.*

## Weathering of Rocks

We have seen how rocks disintegrate to form new rocks out of the sediment. This disintegration is caused by weathering. Weathering is, therefore, the link that completes the cycle between the destruction of old rocks and the formation of new ones. It is the process whereby a rock, as soon as it is exposed above the water surface and comes into contact with the atmosphere, is prepared for breaking up and demolition. Weathering is a widespread and universal phenomenon on the surface of the earth which no rock can escape. All solid rocks, however, hard or resistant they may appear

*The peak of Mount Everest consists of Metamorphic Limestone.

to be, are doomed to destruction unless they are buried deep into the earth's crust or under the sea where the chief ally of weathering—the atmosphere, has no access.

There are two types of weathering to which all rocks are subjected. These are : (*a*) mechanical weathering implying disintegration of rocks and (*b*) chemical weathering implying decomposition of rocks. Mechanical and chemical weathering go on side by side mutually helping each other. Shattering of rocks exposes large surfaces on which chemical weathering can do its work. Similarly mechanical weathering of rocks results wherever crevices have been formed owing to certain minerals being dissolved.

The chief agent of weathering is the atmosphere. Other agents are water, temperature, plants, and gravity. The last is essential in removing material and exposing new faces for weathering. Further pieces of rock may be shattered on falling from cliffs, etc.

Factors on which the rate of weathering depends are (*a*) temperature, whether it is cold or hot, changeable or uniform, (*b*) chemical composition of rocks, whether it is limestone or sandstone, (*c*) the number of joints in a rock. The larger the number of joints the quicker the rate of weathering, (*d*) the vegetation, whether it is grassland, or forest, and whether the surface is bare or covered. (*e*) Rainfall, whether it is wet or dry. Chemical weathering is more effective in humid areas, mechanical in dry areas, (*f*) Finally, the topography ; whether it is mountainous with steep slope or level and uniform.

## Decomposition of Rocks

Simple solution is the first work of water in weathering. It is noticeable only in areas where rock salt and gypsum formations occur. Secondly hydration, *i.e.*, the breaking up of water as a chemical element is very effective. It causes an increase in volume and therefore sets up stress. Formerly the splitting off of third flakes, *i.e.*, exfoliation was regarded as due to temperature changes alone, but Prof. Blackwelder has shown that expansion due to hydration is an important cause of exfoliation. Another effect of hydration is that rocks become softer and so easily eroded. A third process of chemical weathering is hydrolysis or the chemical breaking up of water, which sets free a small amount of hydrogen, which decomposes rocks. A fourth process of chemical weathering is oxidation which chiefly affects iron compounds oxidizing them and changing colours of soils to red and yellow.

Of great importance in chemical weathering is the process of carbonation which is "the dominant weathering process of the humid temperate regions." Rain water dissolves carbon dioxide from the atmosphere, and this solution of carbonic acid is a great solvent. Thus granite, for instance, is composed of feldspar and several

other minerals. Now feldspar is easily susceptible to carbonation and thus causes granite to crumble even though it is ordinarily amongst the most resistant rocks. Carbonation also assumes the dominant role in limestone regions.

## Disintegration of Rocks

The first process effecting the disintegration of rocks is the mechanical effects of rain water, as it falls to the ground with a speed attained through gravity. The soil particles are carried away by rain wash. A second process bringing about the breaking up of rocks is the freezing of water. This is because water expands on freezing and theoretically exerts a pressure of 34000 lbs per square inch at 8° F. Often water gets into the minute joints which are present in all rocks. When this freezes it expands and exerts pressure on all sides and the rock crevice becomes a little wider than before. The process goes on repeating itself with more and more water filling the crevice, until finally the rock breaks.

A third agent of disintegration is the direct effect of temperature change. All rocks are subjected to heating during the day and cooling during the night. This process of alternate heating and cooling is particularly marked in desert rocks. The rock particles are subjected to great strain on this account. Sooner or later this strain is bound to loosen the rock structure. When this loosening has gone on for a considerable time the rock particles fall off leading to rock disintegration. If the rock is broken up along joints into blocks, the process is called block disintegration. If the rock surface has peeled off in flakes, we have exfoliation. If the rock breaks up into component grains, we have granular disintegration.

Organic life also affects weathering. Plants send their roots into the rock and thus loosen the rock structure which is then attacked easily by weathering. Insects also burrow into the rock and thereby provide facilities for weathering. In the case of the plants, however, as soon as they take root on the decayed rock material in more or less a dense growth, they protect the rock against weathering to a considerable extent.

Weathering is facilitated considerably by the existence of *joints* in the rock. The joints are fractures or cleavages produced in the rock as a consequence of differing stresses in the earth's crust. These stresses are due largely to the folding and faulting of strata that are so common in the earth's history.

## Influence of Rocks on Landforms

Formerly the idea was that each type of rock had a particular type of landform produced from it. This impression seemed to be

so simple and natural that some of the old writers, even like Leopoldde Buch, Humboldt, Ami Boue, etc., also believed in it.

As the experience grew, it was, however, noticed that the same rocks did not everywhere produce the same type of landforms. It was in the United States, with their varied climates from the Atlantic to the Pacific, that the geologists saw how the conditions of erosion diversify the forms of relief. Exploration of Africa supported the above view.

It is found very difficult to establish to what extent the differences in rock type are responsible for differences in relief. The problem is made complex because of the differences in climate and in the stages of valley-erosion. Besides, the geological classification of rocks does not take into account their chemical or physical properties as affecting erosion. There are many kinds of granites or limestones, for example. The geological classification aims at representing the *rock of the same age*, or of the same *mode of formation*.

From the geographer's point of view the rocks may be classified as follows :—

| | |
|---|---|
| Compact | Not compat |
| Massive | Schistous |
| Fine grained | Coarse grained |
| Impermeable | Permeable |
| Insoluble | Soluble etc., etc. |

## Landforms

Weathering of rocks gives the earth's surface its relief or landforms. A landform is any element of the landscape characterised by a distinctive surface expression, interval structure, or both, and sufficiently conspicuous to be included in a physiographic description.*

The two main divisions into which practically all landforms fall are *constructional* and *destructional*. Constructional landforms are those produced by accumulation and diastrophism. Volcanism, deposition and soil movement are the processes involved in accumulation. Destructional forms are those resulting from removal of substance. The destructive processes are erosion, weathering and soil movements like landslides and destructive phases of volcanic activity.

Destructional landforms are divided into two groups, reduction forms and residual forms. Reduction forms are the depressions and excavations formed by the removal of substance. Residual forms are those which have not yet been consumed by the processes of reduction. Reduction forms call attention to work already accomplished by the destructive processes. Residual forms, on the other hand, call attention to work remaining to be done.

*Howard and Spock, *Classification of Landforms* (Journal of Geomorphology, Dec. 1940).

## Landforms

*(Constructional)*

| Processes | Forms |
| --- | --- |
| Diastrophic | Plains and plateaus, Grabens, fault mountains. downwarped basins, dome mts, fold and complex mts. |
| Volcanic | Lava plains and plateaus, volcanoes. |
| Weathering and soil movement. | Talus, rock glaciers, land slide accumultions. |

*(Depositional)*

| | |
| --- | --- |
| Fluvial | Plains & plateaus, fans, cones, deltas, flood plains, precipitation forms. |
| Glacial | Moraines, drumlins, outwash plains. |
| Eolian | Loess plains, dunes. |
| Littoral | Offshore bars, beaches, embankments. |
| Lacustrine | Lake plains, precipitation forms. |
| Terraqueous | Cones, terraces. |
| Organic | Coral reefs. |

*Destructional*

| | Reduction | Residual |
| --- | --- | --- |
| Processes | Form | Form |
| Fluvial | Valleys, Strathes, peneplanes | Monadnocks |
| Glacial | Troughs, cirques | Aretes, horns |
| Eolian | Deflation hollows | Yardangs |
| Littoral | Sea cliffs, wave-cut terraces | Sea stacks |
| Terraqueous | Sinks | Natural bridges |

## Influence of climate on landforms

We have seen above how weathering is affected by differences in climate. It is through differential weathering that climate affects landforms. This effect is particularly marked on those landforms which are due to running water. Valley cutting and the angle of slopes are directly related to the amount of run-off water. In otherwise comparable areas, the average angle of valley slope increases with the run-off. As the volume and the velocity of run-off are far smaller, in similar relief, in semi-arid than in humid regions, erosional valleys are farther apart in the former than in the latter region. In addition to its effect on the amount of run-off, the climate affects the type and rate of stream erosion.

Climate powerfully affects the character of the vegetation, which, in its turn, affects erosion. A forested surface normally erodes relatively slowly because of the protective effect of leaf-mould, roots and fallen leaves and trees. Down-cutting of valley bottoms is not correspondingly retarded, however, because roots, logs and leaves do not often feriously block streams, except those that are too small to have much erosive power. By this down-cutting, the local relief and the average angle of slope is increased. When the forest is removed from areas of moderate relief; the relatively steep slopes facilitate slope-cutting and if the ground is not protected by grass or artificial barriers, such as those produced by contour terracing, soil loss by sheet erosion and gullying is relatively rapid. This accelerated erosion soon reduces the average angle of slope slightly.

Although the average slope in humid regions in maturity is relatively steep, cliffs are not common in areas of moderate relief. This is because weathering, slope-wash and development of tributary valleys, take place much more rapidly in warm humid regions than in drier regions. In dry regions, down-cutting is commonly much more rapid than is valley widening, and hence streams develop steep-sided valleys, and canyons. This down-cutting rather than widening in dry regions is partly because much of the water fell at some distant place, perhaps upon some remote mountain side, or during some local shower Slope-wash and gullying are limited to the area where the rain fell, whereas, down-cutting occurs for long distances downstream, far from the area of rain. In humid regions rains are much less local than in arid ones, especially during the cooler months when run-off is the greatest. Consequently, slope-wash and gullying occur much more extensively. In other words, valley deepening and widening proceed together in humid regions whereas in arid regions widening normally lags far behind.

Consequently, where rocks of different resistances occur, steep-sides, buttes and mesas are developed in dry regions of even mode-

rate relief, but in humid regions cliffs are comparatively rare, because weathering is much more active and slopewash and tributary development more abundant.

Although ravine-land (badland) topography is often mentioned as a characteristic of semi-arid regions, this is a somewhat misleading. This topography develops most rapidly, if given a chance, in humid regions. Abundant humidity is, however, so favourable to weathering and plant growth that only small areas in humid regions continue long to have the requisite barrenness associated with such topography. Consequently, in semi-arid regions where plant growth upon steep slopes is hindered by inadequate rainfall and slow rate of soil formation bad lands are more extensively developed, although erosion normally is distinctly less rapid than in humid regions on similarly bare and steep slopes.

Over most of the world, north slopes differ from south slopes in steepness, amount and character of run-off, in rock exposure, and in weathering and erosion. These differences are largely due to contrasts in the climate, which differs distinctly on the two slopes, even though they are but a short distance apart. Slopes differ in their climate because of the following factors :—

1. *Exposure to Solar Heating.* In the northern hemisphere south slopes are more effectively heated than the north slopes. The higher the latitude, the more marked are the differences between the north and the south slopes in solar heating. Near the equator, however, there is little contrast, because the sun is nearly overhead.

(2) *Exposure to Moisture-bearing Winds.* In much of the world one slope receives considerably more moisture than the other. In the trade wind belt, most easterly slopes are wet, while the westerly ones are dry. In the westerlies belt, the opposite is generally true.

CHAPTER XI

# THE MOUNTAINS

MOUNTAIN BUILDING—GEOSYNCLINE—THE ALPS—THE HIMALAYAS—BURRARD'S THEORY—HODGSONIAN CONTROVERSY—ISOSTASY—RIGIDITY OF EARTH'S CRUST—FAULT MOUNTAINS—CIRCUM-EROSIONAL MOUNTAINS—VOLCANIC—MOUNTAINS—EFFECT OF MOUNTAINS ON MAN.

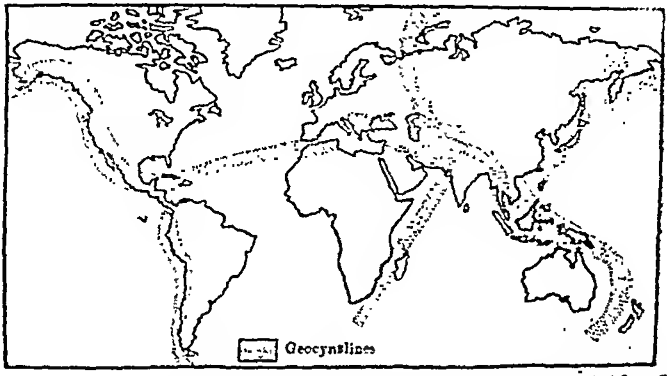
Our ideas about mountains have changed completely during the last hundred years. Instead of regarding them as permanent features of the earth's surface, we now know that they are as transitory as any other form on the earth's surface. Mountains stand at the starting point of the cycle through which passes the whole of the outer surface of the earth's crust. They supply the debris which is carried to the sea to form new rocks. These new rocks are pushed up again, until they form new mountains and supply debris, in their turn, for completing the cycle. A little thought about the great size of the mountains like the Himalayas or the Alps will reveal the hugeness of the material involved in building mountains. For millions and millions of years deposition of sediment goes on in the seas to produce even a small mountain. Considering the height of some of the present mountains, this sediment must be deposited to a thickness of several thousand feet. The present height of the Everest, the highest peak in the Himalayas, is about 29,000 feet. If we consider the millions of years during which the Himalayas have been above the waters of the sea and, therefore, subjected to erosion, the amount of material that has been removed from them must have been tremendous All this material from which such a gigantic mountain was formed lay buried under the sea.

## Geosynclines

There are certain facts about gold mountains which need explanation. In the first place, the fossils discovered in the Himalayas and the other mountains of the world prove that the sediments from which these mountains have been formed were deposited in a shallow sea. This naturally baffles us. How can sediment to a depth of several thousand feet be deposited in a shallow sea ? A shallow sea is at the most about a few hundred feet deep. The deposition of such a large amount of sediment in a really shallow sea ought to have silted it up. But, to our surprise, we find that sediment has actually been so deposited and the shallow sea has ever remained a shallow sea without being silted up ! The only explanation of this is that the bottom of such a shallow sea must be supple enough to yield to the weight of the increasing quan-

tit'es of sediment being deposited. The bottoms of all the shallow seas on the earth, however, do not show this tendency. It is ascribed by the geologists to only a few seas. In such seas the sea floor was continually bending down under the weight of the incoming sediment, forming a great basin or syncline. The name *geosyncline* is given to such a sea floor, and the sea is called the 'geosynclinal sea'.

Secondly mountains occur only in certain well defined belts. The explanation is that geosynclines occur in belts. The following map gives the distribution of geosynclines. It will be noticed that all the geosynclines are not seas today. They are, however, in close proximity to the ranges of mountains that have been built out of the sediment deposited at one time in these geosynclines :—




[*After Haug.*

Fig. 85. Distribution of Geosynclines (Shaded).

In the following diagrams it has been shown how a geosyncline yields under the weight of sediment :—

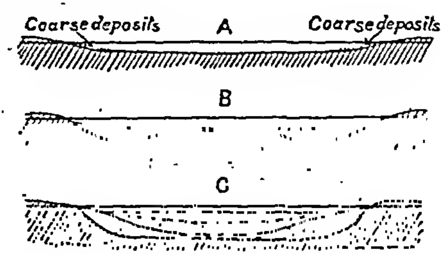



Fig. 86. In *A* the sediment is just beginning to be deposited. The deposit is not yet large enough to cause any sinking of the sea floor.

In *B*, the sea floor has sunk in to parts, but in the middle where the sediment has not yet reached, the sea floor remains as before

In *C*, the whole sea floor has sunk under the weight of the sediment.

## Folding

The sediments are deposited in horizontal layers in the geosyncline. This horizontal character is, however, considerably disturbed while the rock is emerging from the geosynclinal sea. The emergence of the rocks above the sea is due to certain forces, which have

not yet been clearly understood by the geologists. These forces subject the rocks to tremendous amount of continued compression. Owing to this compression, the rock strata are considerably *folded* and *faulted*. Folding and faulting are, therefore,. fundamental to any mountain building.

The old sediment which was deposited in the geosynclines during the past geological time is gradually thrust out in the mountain folds. The emergence of the folds above the water, however, is so slow that erosion has sufficient time to carry off some of the material from them and deposit it as new material along the slopes. As emergence proceeds, this new material is also lifted and folded along with the old. In areas where folding is very intense this new material may be buried under folds of older material and thus render topsy-turvy the arrangement of the rock according to age whereby the older rocks should lie below and the younger rocks on top of them.

In the following diagrams it is illustrated how the folding of the rock strata with the emergence of the rock :—

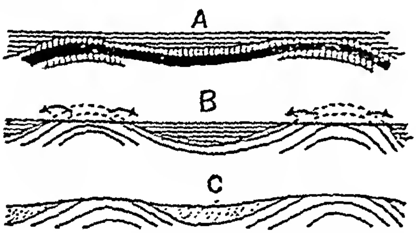



Fig. 87. *A* shows the beginning of folding of rocks which are still under the sea. In *B*, the folds have appeared above the water and are being subjected to erosion. In *C*, the erosing has eaten away the folds above the water and deposited the debris as a new rock (shown by points) in the sea.

In the following diagram the different kinds of foldings are shown.


Fig. 88 Types of folding.

Folding of the strata always takes place against some hard rock which does not yield to the pressure of the force that is folding the sediments. This hard rock is described as the 'thrust plane'. The accompanying diagram shows a thrust plane, the folds and the direction from which the thrusting force has come.


Fig. 89. Rock Folds against a Thrust Plane. SS shows the thrust plane; the arrow shows the direction from which the thrust has come. Points show overlapping folds.

Sometimes, the folding is in simple folds attaining one high point and one low point. The dome shape of the fold where its high point is attained is called the 'anticline', and the trough is called the 'syncline.' The above diagram shows a simple fold with its anticline and syncline.

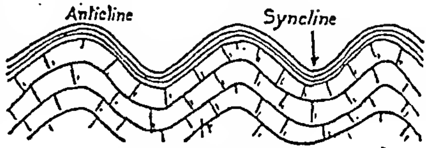


Fig. 90. Simple Fold

Thirdly, mountains did not appear all of a sudden. They do not have a catastrophic origin.

The proof that the mountains rose slowly, and not suddenly is provided by the rivers now flowing in them. For example, the Brahmaputra and other rivers which flow through the Himalayas are believed to have been flowing in their present direction before the mountains rose to their present height. It is believed that as the mountains rose, the rivers removed quickly the rising material in their beds, while the mountain walls on the two banks of the rivers rose high. The river gorges were thus formed. The gorge through which the Arun river flows between the Everest and the Kinchinjunga may have been formed in this way.

Intense folding of the rock places such strain on some parts of the folded material, that the strata break and thus arise the faults. In some cases the faulted strata are thrust forward and lie in positions unconnected with their parent strata. In the following diagrams it has been shown how the strain may develop on certain parts of the rock strata and lead to their faulting :—

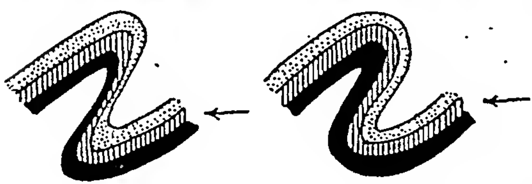
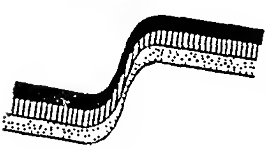


Fig 91. Stages in the development of faults due to overfolding. Arrows show the thrust forward of the faulted strata.



In the fourth place mountain building has not proceeded continuously during the past. There are certain periods in the earth's history in which all the mountain ranges of the present were born. All the highest mountains of the world like the Himalayas,

the Alps, the Andes and the Rockies are a product of the Alpine movement of Tertiary times whose age is computed to be from 30 to 70 million years. Another period of Oragenesis was the Permian, during which the Hercynian movement occurred.

## Isostasy*

There has always been a belief in the existence of a distinct crust of the earth; *i.e.*, there is a difference between the outer and the inner portion of the earth. Observations by seismologists of earthquakes, and observations of tides prove that the interior must be solid, not molten.

It follows from the principle of gravitation that the earth must be a sphere because that geometrical figure has the greatest volume in the least amount of space. But due to varying densities of rocks, the earth surface is not absolutely level the heavier particles sinking down and the lighter particles rising up. That density may have something to do with the irregularities on the earth's surface was first indicated by the fact that the gravitational attraction of mountains is much smaller than their mass warranted. It is a well-known fact that a mountain mass attracts a particle just as the earth as a whole does. The attractions of the mountain mass and the earth are in proportion to their respective masses and inversely proportional to the squares of the distances of their centres from the particle on which they are acting. Archdeacon Pratt [on the attraction of the Himalaya Mountains; Transactions Royal Society, London 1855] was forced to the conclusion that the mountain did not attract the plumb line to the extent that their masses and distances from the observation station would seem to justify. Pratt hinted that there must be a "void" under the mountains. That is to say there must be lighter matter below (deficiency of matter) which, to a certain extent, neutralises the attractive effect of the mountains themselves. It was deduced that mountain ranges are balanced against adjacent lowlands. Isostasy connotes this condition of balance. [Isostasy=equal standing].

There are two interpretations of isostasy. Hayford believed that there was a certain level below the earth's surface called the level of compensation below which all rocks equally distant from the centre of the earth have uniform densities. Above the level of com-

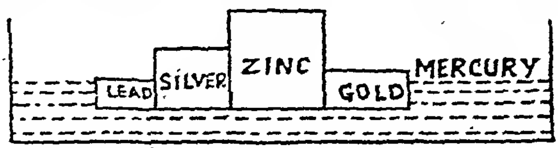



Fig. 92.

*William Bowie, U. S. Coast and Geodetic Survey, Vol. 12, 1922

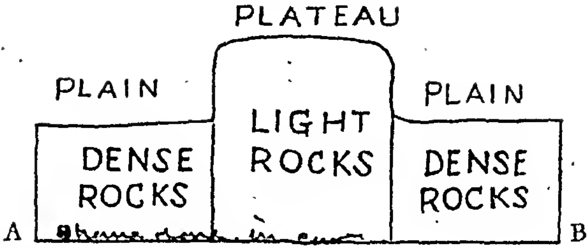



Fig. 93

pensation density varies and adjacent columns of rocks are so adjusted that the height is universely proportional to the density. The figures show Hayward's conception of isostasy as applied to certain metal blocks of equal cross-section and weight floating in a bath of mercury, and also as applied to hypothetical landforms. AB is the level of compensation and the principle is that "the varying volume of matter in the several columns is compensated by their density in such fashion that they exert equal downward pressure at the level of compensation, and thus balance one another."

A second interpretation of the isostatic theory does not hold to the idea of a level of compensation but believes that irregularities on the surface are reflected by irregularities downwards. Mountains are not the result of variations of rock density but of variations in the thickness of the crust of the earth. The idea is illustrated by the laboratory experiment of blocks of iron in a bath of mercury, shown in figure 94 and a hypothetical landform shown in fig. 95.

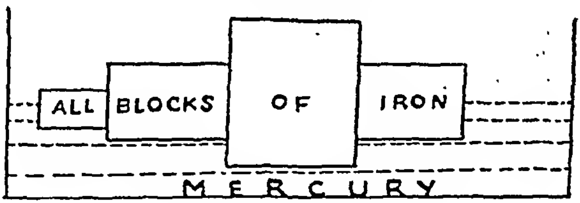



Fig. 94.

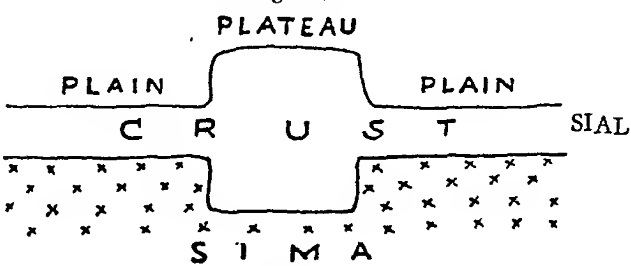


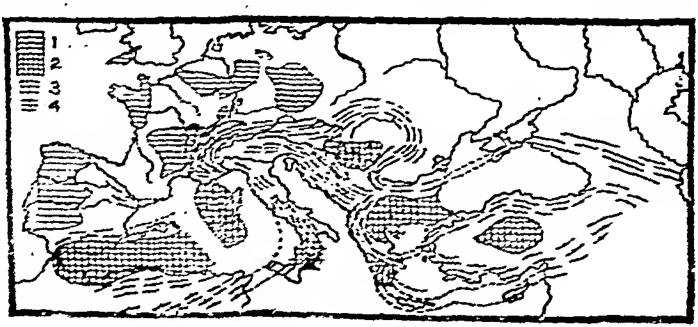

Fig. 95.

## The Alps

The Alps are the best example of Fold mountains, for they have been studied more thoroughly than any other mountain system of the world. We find that the force that built these mountains came from the south, forcing the folds over towards the north. Rivers carried the debris from these new lands thrust above the sea to form deposits to the north. The growth of the early Alps, therefore, led to the formation of the sandstone and conglomerate deposits which now build the Swiss plain to the north of the Alps. As the pressure from the south continued, the mountain folds were forced on to their own debris forming the above plain. The Saentis Mountains south of Lake Constance in Switzerland prove this. The higher parts of this mountain consist of old limestones and shales which rest on newer rocks of the same age as those forming the Swiss plain. The age of these rocks has been proved by the fossils found in them.

The form of the Alps is a curve with its concave side towards the south and the convex side towards the north. This is a clear proof that the compressing force came from the south. The form of the Alps has been determined to some extent by the positions of the harder and more stable rocks to the north and the west. In the map of Europe given below the position of the older hard rocks and their relation to the Alpine and other folds is shown.

The Alps may be thought of structurally as a great mass of sheets of rocks piled one upon the other, each sheet having been brought from the south and pushed forward along a thrust plane. These sheets are called 'nappes'. Some of these sheets have been broken or faulted from their roots which now occur several miles away from the present positions of these sheets. On account of




[*After Suess.*

Fig. 96. Recent Folded Mountains of Europe.
(1 and 2 Hard Rocks; 3 Alpine Folds; 4 Dinaric Folds.)

these nappes, older rocks overlie newer rocks and there occur mountains of rocks which, having been torn from their roots, have absolutely no connection with the rocks occurring miles around them. The Matterhorn is an example of such a mountain. It consists of gneiss rocks which do not occur anywhere near about and which here rest on a much newer rock of the Mesozoic age.

The Alps were only one of the many-folded mountains that resulted from the great mountain activity during the recent Tertiary Age. The line of these mountains may be supposed to continue from the Pyrenees through the Alps and the Himalayas to the East Indies. The same belt may be regarded as continuing in the New World through the West Indies, Mexico and North Venezuela, and through the Cordilleras of North America and the Andes of South America. It is the tops of this belt of mountains that form the Islands of Japan, Philippines and other Pacific islands.

The great series of folded mountains of Asia are, however, supposed to have been caused by a horizontal thrust from the north. The Peninsular India which was then a part of an Indo-African continent (or Gondwanaland) provided the hard rocks against which the strata were folded.

### The Himalayas

The Himalayas are a fold mountain similar to the Alps. The thrust movement came from the north and so the sediments deposited in the geosyncline called the Tethys, began to fold against the hard rocks of the Peninsular India. The sediments began gradually to rise and to be thrown into a series of long parallel wavelike folds.

As the crests of the earth waves rose from the waters of the sea, they were eroded by rain, and other weathering agents, and the rising land became broken and irregular; drainage basins were carved out from the flanks and a river system, composed of 'transverse' valleys was gradually developed.

As elevation continued, the troughs of the folds emerged and a series of 'longitudinal' valleys was established at right angles to the transverse valleys. From the combination of the concurrent processes of elevation and erosion, the existing Himalayas were formed slowly.

As denudation has proceeded, upwarping has followed to maintain the isostatic balance and thus deeper and deeper parts of the crust have been laid bare.

The folds, although analogous to waves, more nearly resemble the breakers on a beach than the swell of the open sea. The form of their surface is rarely that of a simple arch and trough; fold has been superimposed on fold, arches have been overturned until they

are almost horizontal, and whole areas have been so distorted and crumpled, that the details of structure can be found out only with difficulty.

Where the stress has exceeded the breaking strain of rock, the structure has been complicated by faulting; parts of the crust have in some cases subsided, and in others been moved horizontally.

Another cause of complexity is that along many of the planes of weakness and faults molten material has been forced up from below, and has partly absorbed the original material.

According to Fox and Odell the Eastern Himalayas have been produced in two distinct stages and by two different processes.

1. The first stage was the production by horizontal compression of an elevated plateau in approximate isostatic equilibrium. This plateau is essentially the present plateau of Tibet. When formed this plateau extended farther south over the region which is now the Himalayas.
2. The second stage, which is presumably still going on, is one of vertical upwarping of the edge of the plateau to maintain approximate isostatic balance as the rivers cut deeper and deeper valleys into its edge. This stage has produced the extra heights of the Himalayan mountains above the plateau of Tibet. Without the deep valleys and gorges in the Eastern Himalayas, there would have been no peaks towering so high above Tibet.

The proof of the above vertical upwarping is found by Odell in the terraces of the river Dzakar Chu, a tributary of the Arun River. The terraces of this river increase in height in the lower course of the river, like those of the Arun. Traced from Tashi Dzom upstream, the terraces decrease. This is but natural. But after some distance upstream, they begin to increase in height again, and near Rongbuk they are well over 100 feet. This rather remarkable fact about terraces can be explained by the recent gradual upwarping of the Himalayas.

Another proof is provided by the Yaru Chu, another tributary of the Arun. Much of the Yaru valley was occupied recently by a shallow lake of which the marshes to the south and south-west are the remnants. About 6 miles east from there is a long stretch of gravel pushing out from the mountains on to a flat plain. This feature has been recognised as the delta of a stream when this plain was covered by a lake about 300 feet deep. On account of upwarping the lake has dried up.

**Burrard's theory of the origin of the Himalayas**

Burrard (in 1912) advanced his theory of the origin of the Himalayas which postulates a sub-crust, contracting as it cools and

cracking. The sides of the crack (or series of cracks) move apart. The crust overlying the shrinking northern side is compressed by this movement of the sub-crust, the mountain folds of the Himalayas being thus produced. The rift is gradually filled with alluvium of low density. Further shrinkage and cracking causes some of this alluvium to be folded, producing the Siwalik Hills.

### Difficulties in accepting above theory

(1) If the sub-crust is so plastic that complete isostatic compensation may take place within a depth of 75 miles, can it be so rigid as to form, under tension, a wide rift to a depth of 20 miles?

(2) Another difficulty was the direction of thrust that folded the Himalayas.

According to the geologists the direction from which the thrust came can be judged :—

(*a*) by the inclination of the axes of asymmetric folds, which appear as though their upper end had been pushed farther than the lower;

(*b*) by the relative position of more or less horizontally displaced masses, it being assumed that an overthrust is more easily produced than an underthrust;

(*c*) by the curvature in the trend of the folds it being assumed that the pressure must have come from the concave side of the arc.

On all these grounds the Himalayas are regarded to have received the thrust from the north.

Suess regarded the whole of Asia as subject to a push outwards from a centre in Siberia, mountains being thrust up in a series of arcs along the continental margin. The greatest resistance to this outward movement was offered by the rigid peninsula of India.

The alluvium of the plains filled up a great downward trough in front of the main upfold, a 'fore-deep' analogous to the Tuscarora deep in front of the arc of Japan.

### The Hodgsonian Controversy

In 1849, Brian Hodgson, who was then the political resident in Nepal, advanced a theory that the great Himalayan peaks did not stand on a range of mountains, but on spurs projecting from the Tibetan range behind.

The geological survey of India has, however, established that the great Himalayan peaks are not connected by spurs with the Tibetan range, but are separated from it by troughs. The great Himalayan range has been cut through in places by rivers rising

behind it. The isolated blocks into which they had cut the main range were wrongly assumed by Hodgson to be spurs of the range behind.

The highest peaks of the Himalayas stand not on spurs but in the crest-zone of a great range; this is the primary fact of structure. The range resembles a crocodile's back; it is a wide flat arch, with relatively slight prominences, called peaks, and it has no sharply edged crest line. All the highest peaks fall within a narrow zone running throughout the length of the crocodile. Glaciers have cut back between the peaks and created a serpentine water-parting line along the zone. Many of the great peaks stand actually on the water-parting and many stand off it on either side: but whether they are on the line off it, they are all situated in the crest-zone of the range.

The great Himalayan range is not the water-parting between India and Tibet: the streams that flow on the northern side of the Everest eventually find a passage through a gorge in the range and join the streams that flow from the southern slopes. The range which stands behind the Great Himalayan range, and which was regarded by Hodgson as the Indo-Tibetan water-parting, is only a regional water-parting. It separates the streams that flow into the Ganges of Bengal from those which flow into the Brahmaputra of Tibet. But the Brahmaputra and the Ganges eventually unite in India.

Longitudinal troughs separate the Himalayan and Tibetan ranges: and the great peaks of Everest Makalu, Gosainthan and Dhaulagiri are not connected by cross ridges with the range behind them; but Kinchinjunga is so connected. A ridge known as the Singalila ridge, runs from Tibet through Kinchinjunga southwards to the plains of India and at right angles to the Great Himalayan Range.

## Principal Ranges

The plateaux of Tibet and Pamir, etc., have been wrinkled into ranges, and the intervening troughs have been filled with debris and their surfaces levelled by the action of water. The ranges of Asia appear all to belong to one great system. The parallelism of the Kailash, the Ladak, the Great and the Lesser Himalaya and the Siwalik ranges, all of which change direction together, is evidence of interconnection.

The Himalaya is the name applied to the intricate and complex system of mountains that forms the northern boundary of India. Some writers have limited the name to the ranges included betweee the Indus and the Brahmaputra, but any such limitation conveys a wrong idea of the physical unity of the mass. The Indus and tha

Brahmaputra, like the Sutlej and the Ganges, cut across the Himalaya through gorges which they themselves have carved out. The breadth of the Himalayas is about 100 miles and length about 1500 miles.

The ranges of the Himalaya may be classified as follows :—

1. The Great Himalaya, a single range rising above the limits of perpetual snow.

2. The Lesser Himalaya, a series of ranges closely related to the Great Range.

3. The Siwalik ranges which intervene between the Lesser Himalayas and the Plains.

The Himalayan area is divided into five parallel zones :—

(1) The outer zone which is contiguous to the Indian plains and contains the Siwaliks and valleys behind it, was elevated more recently than the Himalayas. The width of the zone varies from 5 to 30 miles, being narrow where the Siwaliks are jammed against the Lesser Himalayas.

(2) The second zone is 40 to 50 miles broad in which the mountains assume (in the Punjab and Nepal) the form of longitudinal ranges running generally parallel to the Great Range. In Kumaun the form is more intricate.

(3) The third zone is 10 miles broad, and is occupied by the spurs of the Great Range.

(4) The fourth zone is 15 miles broad and contains the snowy peaks whose height is above 20,000 ft. With the exception of the low ravines cut by rivers the whole of this zone is above the limits of perpetual snow.

(5) The fifth zone, 15 miles broad, is of troughs of rivers rising behind the Great Himalayas.

*Siwaliks.* The Siwalik range is of so recent a growth that its features are, for the most part, the direct result of crustal deformation, and are consequently very different from those of the outer Himalayas which have been modelled by river erosion. The Siwalik range is cut across by the great rivers of the Himalayas, but no open mountain valleys have been developed by its own streams ; the latter are mere torrents and are enclosed by precipitous walls. Its ridges and spurs are narrower, more sharply edged and more inaccessible than those of the outer Himalayas.

The Siwalik range is important because of its proximity to populated tracts.

It is composed of the same material as the plains of Northern India. The Siwalik zone was formerly the northernmost belt of the flat alluvial region. It has been compressed by lateral action inoat

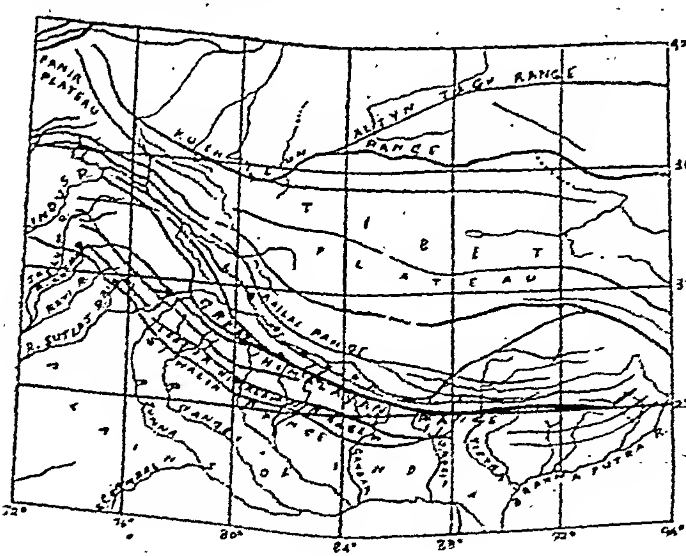
fold or range. The folding of the Siwalik shows that the whole of the Himalayas must have advanced southwards.

With the exception of a short distance of 50 miles, opposite to the basins of the Tista and the Raidak, the Siwalik range has been shown by the geologists to skirt the Himalayas throughout their length, with remarkable uniformity, from the Brahmaputra to the Indus. At the passage of the Sutlej there is a break, not a bend, in the alignment, and the two lengths of the range appear to overlap.

In places, the Siwalik range encloses with the Himalayas canoe-shaped longitudinal valleys called 'Duns'. The best known 'Dun' is Dehra Dun. Other 'Duns' near Kumaun are Kotah, Patli, Kothri, Chgumbi and the Kyarda.

*Lesser Himalayas.* They are an intricate system of ranges. They are the result not of one but of many movements of the crust and their history is more complex than that of the Siwaliks.

In Kashmir and parts of Nepal, flat alluvial valleys are enclosed behind the Lesser Himalayas like the 'Duns' of the Siwalik and like the plains of Tibet. But in Kumaun, though rivers may run for miles parallel to the axis of the mountain, the level and longitudinal valleys are absent.



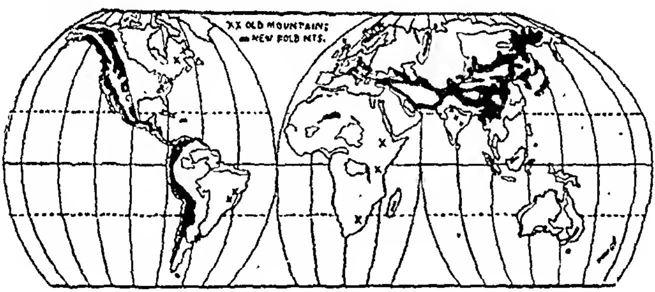

[*After Burrard*

Fig. 97. Ranges of the Himalayan Fold.

*Inner Himalayas.* The Inner Himalayas consist of higher elevations and are characterised by glaciers. The other two zones of the Himalayas do not possess glaciers. The elevations of the higher peaks vary about 20,000 feet above sea level. Most of rivers of the Indo-Gangetic Plains take their rise in the Inner Himalayas and cross by gorges the Lesser Himalayas to reach the plains. An important feature of these mountains is their sudden rise several thousand feet above the plateau of Tibet. The great vertical uplift of Chomolhari, Cancheknhas and Chomoyumo north of Sikkim rising vertically out of the Kampa plain is a remarkable thing.

## Old Fold Mountains

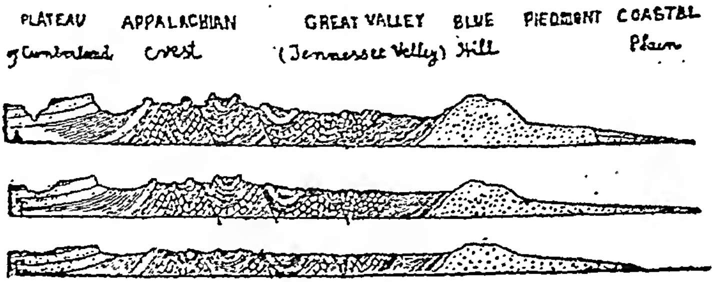
Apart from these new fold mountains, there are remnants of old fold mountains in existence in certain parts of the world. The effect of erosion has, however, reduced these mountains to low heights now. In some cases, these old mountains have been rejuvenated on account of the uplifting movement which they have experienced. This uplift has rejuvenated the forces or erosion working on them as well. The following map shows the old and the new fold mountains :—




Fig, 98. Mountains of the World.

When the rejuvenation affects equally the whole mountain mass, as in the case of the Appalachian Mountains in North America, erosion restarts from the point where it had ceased when the mountain had been reduced to a peneplain. The result of it is that the present features of relief are accentuated. The existing valleys are deepened and the coastal plains are widened. This type of rejuvenation is called the 'Appalachian Type' of rejuvenation. The following diagrams show the same east-west section in three different geological ages. The lowest diagram shows the stage when the Appalachians had been peneplained. The middle diagram shows the rise of the

whole mountain mass in equal degree owing to rejuvenation. The top-most diagram shows the present position of these mountains giving evidence of further rise equally spread over the whole mass. The relative height of the mountain mass above sea level, and the extent of the coastal plain formed by near deposits provide the evidence of rejuvenation of this mountain.




[After Hayes and Campbell.

Fig. 99. Mountain Rejuvenation—A=Actual position to-day; T=position in the Tertiary Age; C=position in the Cretaceous Age.

The Appalachian type is widely distributed on the earth. In India the Aravallis are its most important example.

Sometimes, however, the whole mountain mass is not lifted equally in all places. One part of the mountain mass is lifted more than the other part. This causes the mountain mass to tilt in one direction. The tilted portion is attacked by rejuvenated agents of erosion, while the other portion is not much affected. An example of such a tilt is provided by the Scandinavian mountains.

## The Orogenic Cycle

Mountain building proceeds in well-defined stages which have now to be traced.

(*a*) the preparatory, geosynclinal or lithogenic stage, when the sediment is deposited in the geosyncline,

(*b*) the orogenic stage when the geosyncline is compressed by horizontal forces, and folding and faulting occurs,

(*c*) the epirogenic stage, when the compressed strata begin to be lifted up owing to the isostatic balance. This is also called the

glyptogenic stage from the fact that during this period erosion results in the cutting up of mountains into their traditional forms.

In the first stage eroded material is deposited in the geosyncline, the floor of which subsides, due to the weight of the accumulating sediments. Next, as compression begins, there may be a narrowing of as much as 150 miles as the sides of the geosyncline draw together. The result is that sediment is pushed deeper into the earth. Thus the second stage of folding is characterized by further subsidence. Uplift occurs only in the epirogenic period when the compression is relaxed and the pile of sediments floats up due to isostasy. Further uplift occurs when masses of sediment are eroded away and the mountain mass is cut up, lightening its weight and thus causing further uplift to attain isostatic equilibrium. Thus we see

(*a*) that the first two stages of the orogenic cycle are periods of subsidence and uplift occurs only in the third stage ;

(*b*) that both subsidence and uplift occur in two steps. First there is subsidence due to weight of sediments, next due to narrowing of the geosyncline due to forces of compression. Similarly uplift is in two steps, the first when the force of compression is released and the second when erosion lessens the weight of the mass ;

(*c*) that the height of the mountains is not directly due to uplift caused by folding, but is an indirect result of folding. The direct and immediate cause of uplift is isostatic adjustment. Thus folding of mountains and uplift of mountains are "distinct and successive processes."

## Origin of the Thrust

The force that causes the sediment to fold has not yet been clearly understood. Several hypotheses have been advanced to account for this force. The following are the most important of them :—

(*a*) Contraction of the earth. The hypothesis of the contraction of the earth is based on the assumption that the interior of the earth is cooling and, therefore, must be contracting. The earth's crust thus becomes unsupported from beneath and, therefore, wrumbles to adapt itself to a reduced core.

The chief objection to accepting this hypothesis is the fact that mountain building and consequent folding of rocks has occurred only at intervals during the earth's history. If the folding of the rocks was due to the crust adjusting itself to the reduced core, the

process ought to have been continuous. Moreover, the process ought to have been widespread all over the earth's crust, instead of being confined to certain belts on the earth's surface.

It is significant to note in this connection that the geologists now recognize certain *areas* of *tension* on the earth's surface where the rocks show evidence of stretching. The occurrence of such regions would be impossible if the compression of rocks were due to the shrinking of the earth's crust due to a reduced core.

(*b*) The rate of the earth's rotation was formerly greater than it is now. As the shape of a rotating body is the result of its rotation, any change in the speed of rotation is bound to change this shape. The slowing down of the speed of rotation tends to reduce the excess of matter at the equator by making up the deficiency of matter at the poles. The strains thus set up, might produce the wrinkling of the earth's crust. Geological evidence, however, does not support this transfer of material from the equator to the poles.

(*c*) As the pile of sediments accumulated in the geosyncline, lateral pressures developed according to the theory of isostasy, until the sediment in the filled up basin or the geosyncline was bent in complex folds and heaped in almost horizontally moved sheets or nappes. This hypothesis has received the greatest approval.

(*d*) Wegener's theory of continental drift has often been used to explain the compression of the sediments. Daly used this concept to put forward a theory of continental sliding, leading to the forces of compression. According to Daly, the continent slides downhill towards the geosynclines crumpling the sediments contained in them. The crust beneath the sediments breaks away due to the pressure and sinks into the hot interior where it melts, expands and causes uplift of the folded sediments. Thus compression according to Daly is due to continental sliding and uplift due to melting of the broken crust.

(*e*) Joly expounded a theory based on radio activity, and on the distinction between continents formed of sial floating on ocean floors of sima. After millions of years heat originating in the radio activity of rocks, melts the sima. The result is that the continents sink deeper into the sima and geosynclines or slowly sinking areas come into being. The heat is radiated, the sima cools, and as it increases in density the continents rise, causing uplift of the sediment in geosynclines. Folding occurs because when the sima cools it contracts and creates tensions which fold the sediment in geosynclines.

(*f*) Holmes advances a theory based on Wegener's idea of continental drift, and Joly's concept of radio activity. According to Holmes radio activity sets up convectional current in the sima which through friction against the covering continents of sial, brings about a continental movement resulting in folding of sediments.

## Other Types of Mountains

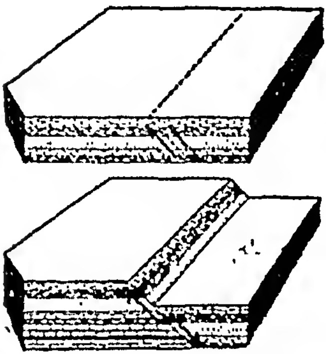


Fig. 100. Tensional Fault. (Arrows show the direction in which the rock moves.)

There are several other types of mountains which have been formed either by tectonic forces like the fold mountains, or by erosional forces. These types are the following :

*Fault Mountains.* Owing to the stresses to which the earth's crust is subjected specially at the time of the earthquakes or other upheavals resulting from earth movement, the rocks are faulted and move away from their roots. Such faults may be caused either by *compressional* forces or by *tensional* forces. Diagrams 101 and 102 give the examples of the two types of faults.

Fig. 101. Compressional Fault. (Arrows show the direction in which the rock moves.)

The movement of the rock mass sideways or downward exposes the fault scarp to erosional forces. It is, therefore, cut into broken topography which presents a hilly appearance. The Western Ghats or the Vindhyas are such mountains. The above diagram (Fig. 100) illustrates the effects of erosion in converting the fault scarp into hilly land.

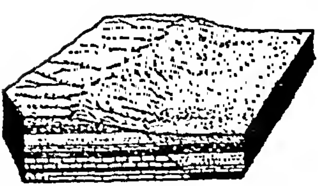


Fig. 102. Erosion of Exposed Scrap.

When there is a double fault and the middle faulted block sinks in relation to the two neighbouring blocks, the forces of erosion working on the raised mass convert them into a mountain. Such mountains are called 'horsts'. The trough or the valley between these raised masses is called a 'fault valley, rift valley or a graben'. The following diagram illustrates how horsts and graben are formed :—

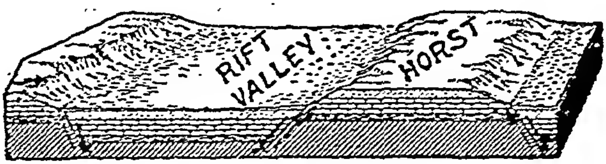



Fig. 103. Double Fault.

*Circum-erosional Mountains.* With the development of erosion when the softer material has been removed, the more resistant rocks stand out above the general surface as hills or mountains. These are called circum-erosional mountains. The following diagram gives the examples of such mountains :—

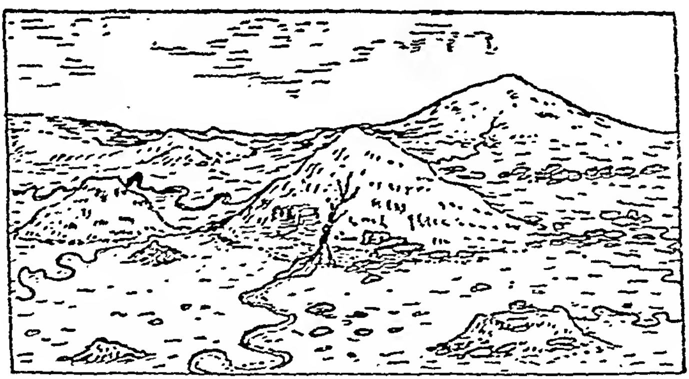


Fig. 104. Circum-erosional Mountains.

*Volcanic Mountains.* The matter thrown out by the volcanoes is deposited around the crater and forms a mountain. If the material thrown out is thin lava it spreads a long distance over the surrounding country and forms a mountain of wide extent, gentle slope and low elevation. The following is the illustration of a volcanic mountain :—

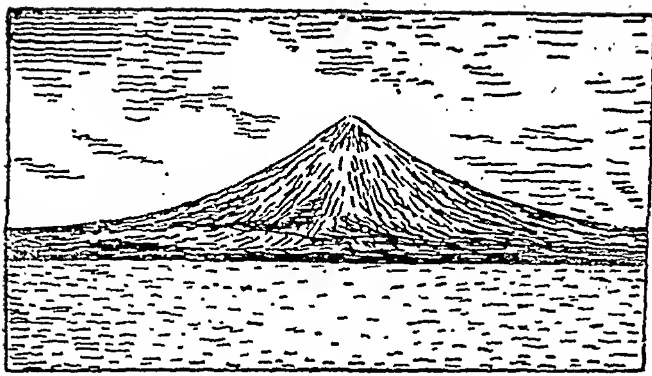


Fig. 103. Volcanic Mountain.

It is clear from the above discussion that *uplift* and *erosion* are the two factors essential for building up a mountain.

## Effect on Man

Mountains have a two-fold influence on man : protective and restrictive. Mountains afford protection against the invasions of hostile people, and thus give peace for the development of the resources and culture. It is to take advantage of this protective influence that defeated people often retire to the shelter of mountains. In the history of every country we have examples where the defeated enemy finds an abode in the mountain fortress. It is because of their comparative inaccessibility that the mountains have protective influence.

Mountains have a restrictive influence on the development of people. Agricultural land is generally limited in the mountainous areas. Man cannot, therefore, develop agriculture as best as he would like to. He has to terrace the mountain slopes to make his fields and to protect the soil from being washed away by running water. In his effort to make the most of the scanty resources of the mountains, man generally becomes hardy and thrifty.

The mountain chains naturally make communications and contact among people difficult. The people living there are, therefore, divided into a number of isolated tribes. These tribes have their own dialect and their own customs and naturally look upon the outsider with distrust. Under these circumstances there can be little social relation or trade among the mountain tribes.

Under the influence of modern civilisation, however, mountains afford great attraction because of their scenery, their bracing climate and the economic resources which were unknown and untapped before. These economic resources consist of mineral wealth, hydro-electricity, forests and building stone. Wherever civilisation has advanced enough, mountain resources have been exploited. This exploitation has resulted in the development of communications in the mountainous areas which have now lost their restrictive or isolationist influence.

CHAPTER XII

# PLAINS AND PLATEAUS

TYPES OF PLAINS—PENEPLAIN—MONADNOCKS—KARST PLAIN —DEPOSITIONAL PLAINS—COASTAL PLAINS—PLATEAUS— EFFECT ON MAN.

Plains and plateaus are distinguished from the mountains by their insignificant or low relief as against the latter's high relief. In the mountains the contrast between the low point and the high point is very great. The highest points of the walls that bound a valley rise to a height of several thousand feet above the valley bottom. In the plains, on the contrary, this contrast is very little marked. The highest point of the ground along a valley in the plains is generally not more than a few feet above it. Another contrast between plain and a mountainous area is that in the plains the passage from one landform to the other is gradual. That is to say, the slopes are gentle. In the mountains, on the other hand, such a passage is abrupt, and the slopes are generally steep. There is another point also that distinguishes the plains from the mountains. The geological structure of the mountains is almost always varied. The rocks composing the mountains are of different ages and of differing resistance. The rock strata that have been folded into mountains are made up of beds of sediments deposited during different geological ages. Owing to folding, however, the arrangement of these beds may be completely upset and a hard rock may lie by the side of a soft rock, or an old rock may lie over a new rock. The diversity of rocks, in the mountains may, therefore, respond differently to the agents of erosion. The plains are, however, characterised by, more or less, a uniformity of geological structure. The surface layer of the rocks composing a plain is usually uniform in structure. It is only in the outcrops, here and there, that a different rock is found. Plains, in fact, result from, more or less, uniform response to relief-building agents.

Thus, the distinction between a plain and a mountain is one of relief and geological structure.

The distinction between a plain and a plateau is not fundamental. Low relief generally resulting from a uniform geological structure characterises the plain as well as the plateau. Some writers have adopted arbitrary elevations to distingnish between the three forms ; plains, plateaus and mounta'ns. Elevations up to 500 feet above sea level, provided the relief is not marked, are classed as

plains; those between 500 feet and 1,000 feet are classed as plateaus; and those above 1,000 feet, provided the relief is well marked, as hilly or mountainous areas. The real distinction between a plain and a plateau lies, however, in the nature of the slope that joins it to the neighbouring type of landform. The plateau has always a steep slope while descending to the plain. This steep slope is known as the 'escarpment' and is almost always considerably dissected by the descending streams. If this steep slope is absent, a land with, comparatively little relief, should always be called a plain whatever may be its elevation above the sea level. An example of such plains is found in the Great Plains of North America.

Plateaus are characteristic of the youthful stage of the cycle of erosion. They are a physiographic form produced by 'degradation' and not 'aggradation'. Plains, on the other hand, may indicate a youthful stage or an old stage in the cycle of erosion. They are, however, more common in the maturer stage of erosion. Plains may be 'degradational' as well 'aggradational.' That is to say, they may be produced by cutting and removal of rock which levels *down* high ground, or by deposition of rock which levels *up* depressions.

## Types of Plains

Plains may be roughly divided into:

(*a*) Peneplains (also called 'destructional plains').

(*b*) depositional plains, and

(*c*) coastal plains (also called 'constructional plains').

## Peneplain*

When a mountain mass has been subjected to erosion for a considerable degree and the rivers have almost reached their baselevel, the resulting plain is called a 'peneplain'. A mountain is thus 'reduced' to a peneplain through erosion. A peneplain may still have some isolated hillocks which are the remnants of harder rocks that the streams have failed to wear down. But the greater part of the plain consists of valley flats and the gently sloping uplands between them. When a peneplain has been eroded to about the sea level and the rivers cannot, therefore, cut the rocks any more, the peneplain is called the baselevel. In the development of a peneplain the streams remove the weathered rock from the higher slopes and thus level them down, and deposit it in depressions which are levelled up. Levelling down of higher slopes and levelling up of depressions produce a peneplain.

*Peneplain means *nearly* a plain.

Undulating surface and a few hills, here and there, in areas of unusually hard rocks, or in positions so situated as to be less assailable by stream erosion, characterise a peneplain. The hills in a peneplain are called *monadnocks*.

The peneplains that exist on the earth's surface today do not, however, show the typical conditions of a peneplain. Their surfaces are rolling with comparatively higher slopes than give a peneplain, while their elevations are such as to give considerable cutting power to the streams. This change in the typical peneplain is due to the crustal movement which results in the rejuvenation of old mountains.

The most important examples of peneplains in the world today are the central plains in Russia, plain of eastern England, Paris Basin, southern part of the Amazon Basin and the upper regions of the Mississippi Basin. In India, the most important example is the Aravalli region west of Delhi.

The form of the peneplain depends largely on the geological structure of the region. If the structure is uniform, the stream erosion will affect the whole region alike and there will result, therefore, a uniform relief. If, on the other hand, hard and soft rocks lie side by side the stream erosion affects them differently. The softer rocks are eroded quickly and present a flat surface, the harder rocks resist and stand out as ridges above the flat surface. With the progress of erosion which now attacks these ridges with greater vigour,

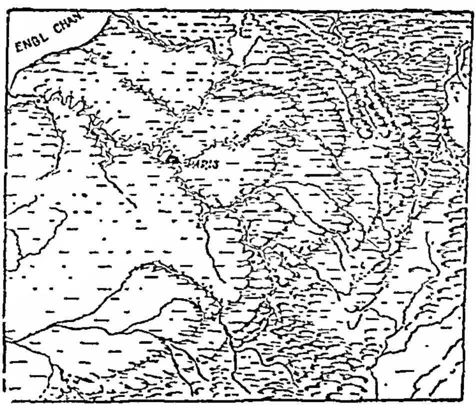



Fig. 106. Paris Basin.

because of their elevations, than the adjoining flat lands the ridges are broken through in time. The streams now cut the material

from the ridges and deposit it on the flat land. These ridges give a banded appearance to the peneplain resulting from the erosion of hard and soft rocks lying together. The ridges have been called 'cuesta' and the plain, as a whole, is described as a 'cuesta plain'. The Paris Basin of France is an important example of a cuesta* plain. In the preceding map showing the Paris Basin, the ridges stand out prominently with their steeper slopes away from the plain. The ridges are more numerous at the periphery of the plain. The central and the western part of the plain is flat and it is here that the debris brought down from the ridges has been deposited. The Sein and the other rivers near Paris are encased by steep banks, but the rivers flowing in the western part of the plain have low banks.

## Karst Plain

Karst plains may be considered under peneplains, because their development is due to the erosion of water on a particular type of rock. A mature Karst plain where impermeable rock underlying the soluble limestone has been exposed and the surface flow of the stream is resumed, presents all the peculiarities of a peneplain: flat ground, gentle slopes of river banks and hillocks provided by the remnants of limestone. Karst plains are the work of underground water. There is, therefore, little water to be seen on the surface. Where there is a big river coming to the Karst plain from an adjoining area or where the water sinking underground in the limestone issues forth in the form of a spring, the soluble rocks are entirely removed exposing the impermeable strata. Except in such areas, flow of water is absent in a Karst area.

The outstanding features of a Karst plain are the sink holes, caverns and natural bridges which result from the collapse of the roofs of the caverns.

The most important examples of Karst plains are found in Yugoslavia along the Adriatic sea, in southern France, Florida and Mexico in North America and in Cuba.

Karst plains are developed in many limestone or dolomite regions, because these rocks weather differently from others. The difference is principally due to the solubility of calcium carbonate in natural waters. The first solution channels owe their pattern to the highly developed system of joints which is nearly always found in such rocks. In a region where Karst topography is fully developed the water circulates almost entirely underground.

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*The word 'cuesta' has been taken by W. M. Davis from the Mexican-Spanish, meaning a ridge with abrupt front on one side and a gentle slope on the other.

## Drainage and the Karst Cycle

The evolution of landforms in such a region follows, step by step, the evolution of the subterranean drainage. Up to the appearance of the article of Civijic* two divergent theories as to the circulation of underground waters held the field; that of Grund and the other of Katzer.

Katzer's theory regards the subterranean waters as circulating continuously, all irregularities being explained as due to siphons which force up the water, the stagnant water being regarded as a merely temporary accident. The other theory (of Grund) holds that there is a *saturation level* in the limestone mass, below which all the crevices of the limestone are filled continuously with water. The only circulation that exists is the descent of the rain that passes through the porous limestone until it reaches the saturation level, after which it is stagnant.

Many phenomena, such as the successive displacement of springs and the change of level and final desication of the temporary lakes that are found in Karst regions, are difficult to explain by either of these theories.

Civijic considers that in a fully established Karst system there are three hydrographic zones :—

(1) The zone immediately beneath the surface is composed of channels and reservoirs which transmit water in time of storm but are usually dry.

(2) The next zone is intermittently dry and wet; its caverns and channels may be flooded for considerable periods but not permanently.

(3) The lowest zone, situated immediately above the junction with the underlying impermeable strata, has permanent streams and reservoirs which are always full of water.

There are many modifications of the ideal scheme due to geological structure and other causes. Normally, the youthful stages of a Karst region is marked by the development of underground drainage so imperfect as to leave a large amount of water that falls as rain remaining on the surface of the ground, although all the cracks and crevices of the rock are filled with water. In this stage permanent lakes exist.

In the next stage the subterranean system is sufficiently developed to carry off all the surface water except in times of exceptional downpour. In this stage intermittent lakes are found.

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*J. Civijic, *Karst Topography, Geog. Review*, 1924.

In the perfectly developed system all the surface water is carried immediately underground, and consequently no lakes are found, unless the depressions of the surface are so deep that they dip below the upper level of the saturated zone.

### Landforms and the Karst cycle

With the development of the underground develop the landforms of the surface. Civijic distinguishes three phases in this development: youth, maturity and old age.

In youth, the surface of the land is still principally drained by the rivers which flow on the former surface of the land before the limestone subject to karsting was laid bare, or when it was at lower level or had a better climate and denser vegetation and normal surface erosion took place. This earlier development of normal surface drainage is an important feature of Civijic's explanation, youth being marked by a progressive loss of surface drainage. Rivers flowing above ground disappear, and in some cases the disappearance takes place in a few decades. Wherever the limestone is exposed to the rain the ground is covered by a network of furrows eaten out of the rock by the dissolving water. There are many terms to denote it: 'rascles' Karren or Lapiez. Where any line of weakness, such as a fault or bedding plane or joint, allows the water to penetrate more easily, deep and narrow chasms are produced. They are known as 'bogaz'.

Such are the beginnings. Little by little, however, the furrows and chasms are deepened, underground channels are created. Often in the course of a stream such a chasm appears, and soon the streams disappear down the holes, leaving their valleys dry. A valley that is deserted by its stream in this way is called a 'blind valley'. The holes down which the streams disappear are roughly of two classes; those that are funnel-shaped and those that are cylindrical. They are called dolines or sink holes.

In the youthful stage the limestone mass is traversed by innumerable fissures, but no great caverns are as yet formed. The development of the underground system of drainage is far from complete. In the early stages of youth only one hydrographic zone is established; although towards the end of youth two zones may be distinguished; an upper zone which is flooded intermittently and lower one which is always completely saturated.

The stage of maturity is reached when subterranean drainage exceeds surface drainage. In this stage underground drainage is fully developed and all three hydrographic zones are present. In this stage also the divisions between neighbouring funnel-shaped holes (dolines) are broken down and larger depressions are created.

These are called uvulas. Caverns are a characteristic feature of this stage, being due to solution by underground water. When the roofs of these caverns fall in, cylinderical dolines are formed. In many of these caverns evaporation of water dripping from the roof results is the formation of stalactites and stalagmites.

As the course of erosion proceeds, both the surface and the underground systems are modified. The higher land separating the major holes is dissolved away, and manv sketches of flat land are formed. This flat land is surrounded by higher land which shows holes. The underground drainage is now fully developed, a network of caverns and chan els permeating the entire mass of limestone. These channels are sufficient to carry off all the water that falls as rain, and there are no permanent surface lakes. Terraces of alluvium surround the former lake basins.

The mature stage may be said to have passed, the moment any part of the underlying strata is laid bare. Now begins the decline of late maturity during which the limestone is gradually removed from underlying impermeable strata. Surface streams now appear. At first they are not above ground for any long distance. The streams issue from a cavern and frequently flow into another. Then cavern after cavern falls in, and gorges are created everywhere, the edges of the plateau suffering more than the interior. In one way or another and with many possible combinations of structural and hydrographic conditions, the limestone surface, riddled with holes disappears in places, and great flat bottomed depressions, poljes are formed. Their floors become covered with alluvium as the water courses work down to underlying impermeable strata, or reach normal baselevel. According to another view poljes are not a result of solution but on the other hand they are graven like faults. In addition to reappearance of surface drainage and the development

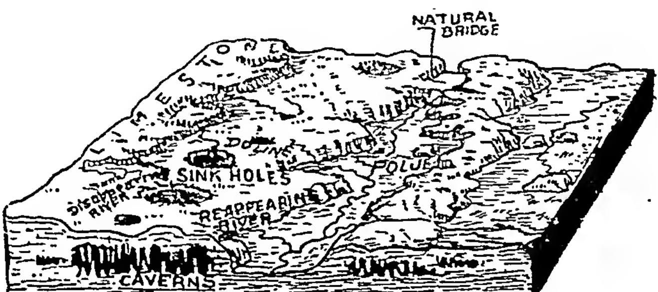


Fig. 107. Karst Topography [*After Cirijic*]

of poljes a third characteristic of old age in a Karst cycle is the existence of residual mounds of limestone, called hums. Such is the development of Karst topography. The following diagram shows the various features characteristic of this topography.

## Depositional Plains

The material eroded from elevated areas is transported and deposited in depressed areas by the agents of erosion. This deposition builds plains which may be called 'depositional plains'. The most common depositional plains are those associated with streams. They are built with the alluvium brought by the stream and are described as 'alluvial plains'. Finch* divides the alluvial plains into three classes: the delta plains flood plains and plains of older alluvium. They are essentially related to the development of the river valley and can, therefore, be considered under the following three heads:—

(i) Upper valley plains, (ii) middle valley plains, and (iii) lower valley plains.

(i) When the river emerges from the mountains its valley broadens, and owing to the reduction in the speed and the carrying capacity of the water, the silt brought by the river is spread over the adjoining land. The volume of water which was confined to a narrow valley of the mountains is now spread over a broad area, over which the silt held by water is deposited. At this stage, the plains are largely composed of sand and gravel and plenty of boulders are strewn on the surface which are brought by the flood waters following torrential rains in the mountains. Such plains are called *Bhabar* plains in India.

(ii) As the river proceeds in its downward course, it builds a wider plain for itself out of the coarse material of the Bhabar plain which is then ground finer as it is carried downwards. Some of the finer material held by the river water that was not deposited in the Bhabar is also deposited in the middle course, owing to a further decrease in the speed of water. The river is joined in its middle course by a number of tributaries which also bring material for the building up of the middle-course plain. The plains of the tributary rivers are joined to the plain of the principal river in its middle course. This fact results in still further broadening of the middle plain.

The middle plain is, therefore, marked by a number of *doabs* of inter-riverain plains. The doabs are formed by joining together of the river banks and, therefore, have an undulating surface.

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* *Elements of Geography*, 1936, p. 341.

A characteristic feature of the middle plains of some rivers is provided by *river terraces*. These terraces are small flat alluvial plains situated at some height above the present plain. They are also called *benches*. These terraces are the remnants of the older plain which has now been cut away owing to the river erosion. The formation of the terraces is due to rejuvenation of river erosion which may have been brought about by some cause. Owing to the rejuvenation the river alluvium that had been deposited by the river at one time begins to be eroded now. The result is that the river builds for itself a new plain at a considerable depth below the old plain. The adjoining diagram illustrates the formation of river terraces.

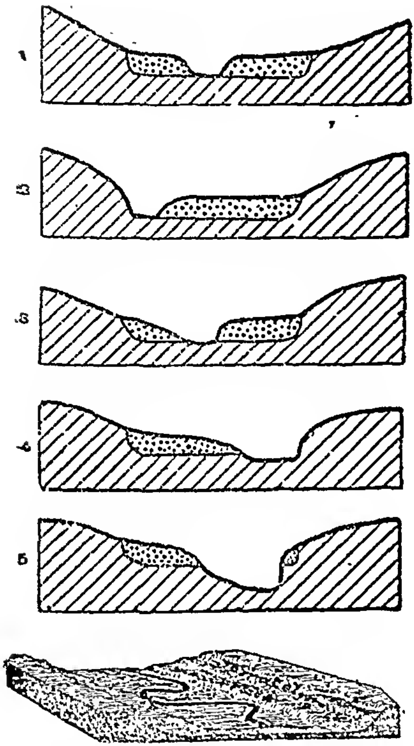

Fig. 108. Formation of River Terraces.

In Nos. 1 to 5 the dotted portion shows the old river plain which has now been eroded. Only part of it is left as a terrace in the 6th diagram.

(*iii*) The plains of the lower course of the river are the most permanent, in so far that it is here that the river approaches the grade or the base-level. Cutting is, therefore, almost entirely stopped in part. The carrying capacity of the river current diminishes considerably and deposition of the material carried by river water is the dominating features of this parr of the river valley. This plain is marked by its flatness which naturally results from deposition. The river banks are not very high and the flood water of the river, therefore, spreads far and wide over this plain. The alluvium deposited by the flood water adds further to the flatness of the plain.

## River Meanders

When the river starts its life as a gully, its course is not quite straight. It is slightly curved here and there following the natural curves that are present in the uplifted land. During the process of

down cutting when the river makes its V-shaped gorge, it comes across weak and resistant rock structures simultaneously. Wherever in the above curves the rock is weak, it is cut away quickly, and the curve is thus widened while the river is still down-cutting. Wherever the rock is resistant, it is cut less, and therefore, juts out into the river from the side. These jutting out resistant rocks alternated by wider curves provide the first meanders to the stream. The jutting pieces of rock from the valley walls are called spurs. The spurs from the two walls of the river can fit in and are known as interlocking spurs. They also overlap the stream.

As time passes and down-cutting in a stream becomes less prominent the jutting spurs receive greater attention from it. Because of the curves in the stream flow, the spur on the side receives greater force of the flow than a corresponding spur on the other side. This full force is felt on the curves not only outward but also in a downstream direction. The interlocking spurs on both sides are thus undercut and paired off. In the meantime the slopes of the spurs have also been lowered due to weathering. The result is that during floods part of the spur is completely covered by water and is cut off in due course. The spurs are thus blunted. The floor of the river valley is now widened and is comparatively flat. Along the sides of this flat valley large quantities of debris are deposited by the river, especially during the floods. A flood plain is thus formed.

The widening of the river valley and the consequent formation of the flood plain increases the tendency of the river flow to form meanders. The river water is now loaded with silt more than before, for it has become older. Even a small obstacle, say a big boulder, would turn the flow and cause deposition. Meanders are easily formed and frequently formed at this stage. The meander formation is, however, confined only to a certain part of the flood plain. This part of the flood plain is called the *meander belt.** New meanders are formed and old ones destroyed across the whole of this belt. The size of this belt is generally proportional to the size of the stream. Smaller streams have a meander belt about 50 feet across; larger streams have a mile or more. A convenient estimate of the size of the meander belt is about 15 to 20 times the width of the stream current. When the meanders attain the maximum size appropriate to the size of the stream they become S-shaped (known as dovetail meanders). Soon the ends approach intersection of the curves and result in the cutting away of the neck of the land between them. The stream, therefore, takes a new course across the inter-

*The meander belt is measured from the median line of flow to the centres of the arcs of successive meanders beyond which the meander curves cannot be enlarged.

section. The former roundabout flow is abandoned by the stream for some time, but the development of new meanders starts again. The abandoned meander course becomes an oxbow lake (called also mortlake) or a marsh which remains until the next flood.

When cut-offs become a common occurrence, because a continuous flood-plain exists now across the full breadth of the meander belt, the stream acquires a regular swinging flow. From time to time, the current now swings in new directions because of cut-offs. The streams now become a stream of free meanders. The meanders now move not only across the meander belt, but move freely down the course of the stream. The examples of meandering can be seen in any large river in U. P. in summer when the amount of water in the stream is less in relation to the amount of silt carried by it. Swinging and down the course shifting meanders become common.

Limited meanders of the upper valley and free meanders of the lower valley are thus the two classes of meanders.

Meanders are common to all rivers of large size. The outstanding fact about the lower valley of a river is that the river has lost its power of cutting the bed. The only place where some cutting goes on is along the river banks where the *mass* of water, rather than the *velocity* of water, combined with the looseness of the soft alluvium produces bankslides rather than erosion. Owing to this loss of cutting power the river tries to avoid any obstruction in its course, if it cannot remove it easily. This avoidance causes a bend in the river. This bend becomes wider and wider until a curve or meander is formed. The obstruction in the flow of the river is provided by the silt that is being deposited fast.

The same factor (avoidance of obstruction created by deposited silt) which brings the meander into existence also tends to destroy it by cutting off the main river current. We have mentioned above that the meanders have a tendency to widen. This widening goes on until the two ends of the meander meet and let the stream resume its straight course. The meander that is cut off from the main stream in this way forms a lake called *ox-bow lake* or mortlake.

The meandering stream flows with different speeds in different sections of the meanders. It flows with greater speed in the concave curve than in the convex curve. It will be seen from the following diagram that in the convex curve the flow of water is against the general slope of the valley plain. This fact considerably lowers the speed of the flow in the convex section of the meander, because it is against gravity. In the concave curve the flow is greater not only because it is in the direction of the slope, but also because *inertia* or the centrifugal force helps it. This force implies that all movements tend to continue in the initial direction. In the case of the river

the initial direction of flow is towards its mouth. The concave bank of a meander is steep; while the convex bank is formed by deposition by the river and consequently slopes gently downwards to the water.

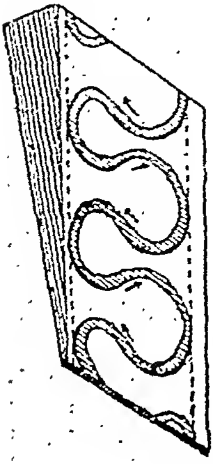

Fig. 109. River Flow in Meanders.

The following diagram shows the concave and convex banks of meanders, the arrows showing flow against gravity. The concave curve is marked by thick line, while the convex curve is marked by thin line

The following diagrams show the various stages in the development of a meander. Meanders become *incised* when the dominant down-cutting force is either due to rejuvenation of the stream or due to rock structure. If the incision takes place quickly the meander is known as "Intrenched." Its cross-section is symmetrical. If the incision is slow-giving lime for lateral shift, the meander is called "Ingrown" meander and its cross-section is not symmetrical.

### Delta

Where the river empties into the sea or lake the coarser material is deposited immediately at the mouth of the river. The finest material is, however, carried by the river into the sea. This mud that is held by the fresh water of the river settles down quickly as soon as it mixes with the saline water of the sea. The middle portion of the river water has greater speed than the water on the flanks and penetrates farther into the sea. The water in this part of the river, therefore, comes into touch with the saline water later than the water on the flanks. This fact leads to the settling of the mud earlier along the flanks than in the midstream. The result is that the mud deposition projects into the sea like a tongue. As time goes on, the mud so deposited builds a plain which, in due course, rises above the surface of the sea. This plain is called the delta after the Greek letter which corresponds to the plain built in this way by the Nile, with which the Greek geographers who invented this word were most familiar.

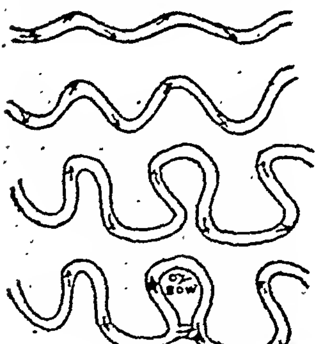


Fig. 110. Formation of Meanders.

Topographically, the delta consists of three parts :—

(1) a broad, gently sloping upper surface most of which is above the level of the quiet water called Topset;

(2) The steeper front slope which is submerged called Foreset;

(3) The submerged muds extending out in a gently undulating sheet from the foot of the front slope called Bottomset.

The plan of a delta depends upon several factors among which the presence or absence of longshore currents and variation in the load transported are important. If these disturbing factors were not there the delta would be a semi-circular one. Longshore currents sweep away much of the material brought by the stream and so *truncate* the delta. When the load is diminished, the distributaries may temporarily degrade their channels, bear the resulting sediment to the front, and drop it there as small deltas. This makes the main delta a *lobate* delta. Highly irregular delta fronts show that river construction dominates over wave erosion.

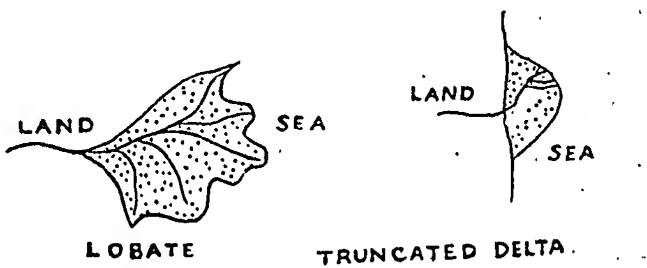


Fig. 111

If the river is stronger, the delta will encroach upon the sea; but if the waves are stronger, they may carry away and spread the delta deposits below water level.

Provided there has been no erosion of the foresets, the junction between any foreset and the immediately overlying topset bed is a little below the water level at the time that foreset bed was deposited. This is because the stream can maintain its current for a short distance out from shore.

Uplift and depressions of the sea floor may have significant effects upon marine deltas. Slow subsidence results in great depth and volume of topsets; while small uplifts favour great volumes of foresets and tend to shift seaward the zone of terrestrial sedimentation.

The delta plain is a continuation of the lower valley plain of the river. It has a tendency to enlarge and to grow towards the sea. Excavations at Cairo (the apex of the Nile delta) have shown that it was there that the Nile joined the sea at one time. Today, however,

it joins the sea about 100 miles further north. The extension of the delta is brought about by the stream flow dividing itself into branches owing to the obstructions created by the deposition of mud. As the speed of the flow is lower at the flanks than in the middle, the river begins to deposit mud at its sides. This mud, in due course, forms natural levees or banks. The river flow begins to feel the impediment of these levees, and, therefore, it branches, flowing on both sides of the levee. In time to come, levees form along the new branches as well, and these result in further branching of the stream flow. The mud deposition thus extends fanwise, giving to the delta a digitate or fingerlike appearance.

The formation of the delta is associated with only those rivers that drain into a sea or a lake where the tides are not strong, and the river brings large quantities of mud. Strong currents and tides carry away the mud deposited by the river and thus check the formation of a delta.

Currents sometimes modify the shape of the delta by deflecting the mud to one side. The mud so deflected forms a spit between two branches which are converted into a lagoon. The most outstanding example of such a modification is provided by the Nile delta where the east-flowing currents in the sea have built up a spit of land from the Rosetta branch thus enclosing the Borollos Lake. A similar spit from the Damietta encloses the Menzala Lake. The following diagram shows the delta of the Nile :—

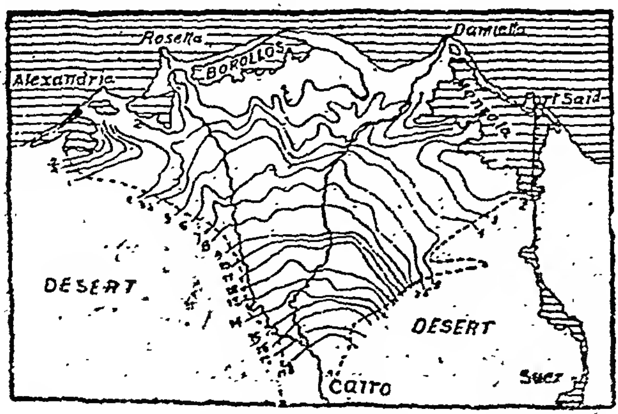


Fig. 112. Nile Delta.

(Dotted line shows the limit of the delta ; the Continuous lines across the delta show height)

The above diagram of the Nile delta may be compared with the adjoining diagram of the Ganges delta in which the absence of ocean currents maintains the fingerlike shape of the delta.


Fig. 113. Ganges Delta.

The delta formation is the result of the conflict between silt deposition by the streams and silt removal by the ocean currents If more silt is brought than can be removed, a delta is formed. If for one reason or the other the silt brought down by the river decreases, so that the amount coming to the sea is quickly removed by the currents, the process of delta formation is enfeebled. This is the case with the delta of the Nile today. The silt brought down by the Nile is now washed away by the ocean currents towards the east to the Syrian coast. Such a delta is called a *blocked delta.* When, however, the amount of silt brought down is enormous, the process of delta formation is rapid. Such a delta is called a *vigorous del a.* In vigorous deltas small islands appear a little distance away from the river mouth. Gradually these islands enclose a lagoon which quickly fills up. The digitate form (also called 'birdfoot' delta) is the most common form of a vigorous delta. The Mississippi delta is the most important example. Fig. 114 on the next page shows the digitate form of the Mississippi delta.

## Coastal Plains

We have so far discussed the plains which are of erosional or depositional origin. In both cases the origin was due to external forces of nature. Coastal plains are, however, due to internal forces. They are lifted bodily from below the sea adjoining the coast. These plains must be regarded a part of the 'continental shelf' which is raised above the coastal seas due to diastrophism or the warping of the earth's crust. It is known that land does not end abruptly at the coast. It continues to some distance under the sea. This continuation of the continent or land under the sea is called the 'continental shelf'. The presence of the 'continental shelf' is indicated by the abrupt end of the shallow sea. It is noticed that for some distance the depth of the sea water increases only gradually, but beyond a certain point the water becomes very deep suddenly. This point

marks the termination of the continental shelf. Upon this continental shelf is spread the mud and silt brought by the rivers. When

U. S. Coast Survey.

Fig. 114. Mississippi Delta.

the sea recedes owing to a change in the sea level, part of this continental shelf is exposed as the *coastal plain.* It is bounded towards the sea by the present shoreline and towards the land by the old shoreline.

The coastal plain shows in the beginning all the characteristics of maturity, that is to say, it has no marked slopes. It presents more or less a flat surface, diversified, here and there, by lagoons.

It is a low and almost reliefless plain in which the alternating layers of sand and mud lie almost horizontally.

The flatness of the coastal plain is, however, only temporary. As soon as erosion starts in this plain the usual features of relief connected with it (erosion) gradually appear. Running water from the interior of the land finds its way into this plain and carves out a valley. Rainwash also develops gullies and hollows. The work of erosion in the coastal plain is generally easier owing to the soft, uncompacted and horizontal layers of sand and mud. The seaward approaches of the coastal plain are marked by sand dunes. The landward approaches are, on the other hand, often marked by steep slopes of the old shore. These steep slopes cause waterfalls in the rivers that now flow beyond them to the sea. The Fall Line in the United States of America is the most important example of such falls.

Among the many examples of coastal plains may be mentioned the Coromandal coast of India, south-eastern coastal plains in the United States of America, and the plain along the Guinea coast in Africa.

## Plateaus

The plateaus occupy an initial stage in the cycle of erosion. They are intermediate between the hills and a peneplain. The elevation of the plateaus encourages rapid erosion and soon they are reduced to peneplains. The origin of the plateaus is generally the upthrusting movement caused by internal forces of the earth. When a peneplain is elevated due to vertical uplift, so that it has a steep scarp it becomes a plateau. The steep scarp is later eroded into a number of gullies. Owing to this vertical upthrust the rivers of the peneplain are rejuvenated and begin to carve their valleys deeper and deeper. The surface of the plateau is, thus, broken into a number of deep gorgelike valleys. There are some hillocks standing out prominently, bearing evidence to the past peneplaination of the area.

The plateaus are generally classified into the following classes :—

(*a*) Intermontane plateau,

(*b*) Piedmont plateau,

(*c*) Continental plateau.

(*a*) The intermontane plateaus of the world are situated at great heights. They are found at elevations above 10,000 feet. These plateaus are usually small in extent and are situated in the midst of high mountain ranges. These plateaus were lifted up along with the mountain folds. The most common examples of such plateau occur in the Rockies and the Andes mountains.

(*b*) The piedmont plateaus are situated at the foot of mountains and are due to the same uplift that brings into existence all other types of plateaus. These plateaus are usually very small, smaller than even the intermontane plateaus. The only important example of such a plateau is the Patagonian plateau in South America.

(*c*) The continental plateau may be due either to a general uplift movement, or, as in the case of the Deccan plateau of India, to the pouring of lava sheets of great thickness. The continental plateaus are the largest of all the plateaus. Much of Africa, Arabia, Spain, Australia and India is classed as continental plateau.

## Effect on Man

Plains occupy the largest portion of the land area of the earth. Their influence on the life of man is, therefore, very important. We find today that the largest part of the world's population lives on the plains, the biggest cities of the world are found on the plains, the most important agricultural regions of the earth are found in the plains, and the greatest network of communication lines covers the plains. All this is due to the fact that most of the plains of the world offer the easiest conditions for the early progress of man.

Most plains in the world are endowed with a fertile soil. The climatic conditions also favour, together with the fertile soil, the development of the earliest agriculture on the face of the earth. This fact naturally attracts people to settle down on plains. The effect of the general suitability of the plains to agriculture has been the most important in attracting populations. This can be illustrated by contrasting the position of the plains unsuited for agriculture in respect of population. There are dry plains unfit for agriculture, and they are among the most thinly populated parts of the world. Contrast the position of the Sind plains in India with those in Bengal in the distribution of population. Sind has the sparsest population in India, while Bengal has the densest.

Plains facilitate movement and, therefore, encourage exchanges of ideas, commodities, and people between one part of the plain and the other. The relief features in the plains never offer much obstruction to the lines of communications. On the other hand, the rivers, without which there are few plains, provide almost ready-made natural lines of communications. The rivers are the first lines of communications along which any large movement takes place. Owing to this facility, the towns first arise on river banks. Greater the traffic on the river, larger is the importance and size of these towns. The more fertile the plain, the greater is the traffic that is produced by it. The level or undulating topography of the plains

leads to the building of railways and roads. The slopes are gentle and the gradients small. This fact makes the building of railways and roads in the plains less expensive than in the mountains. There are few detours to avoid obstructions that the railways and roads have to make in the plains. The cost of construction is lower in the plains on this account also.

The richness and the accessibility of the plains have, however, always led to invasions and warfare. There are hardly any rich plains in the world which have enjoyed peace for any considerable time in the past. The North European plains, the Chinese plains and the plains of the Indo-Gangetic basin have been 'bones of contention' to a great extent in the past. These rich plains are in the vicinity of areas with few resources and have, therefore, always offered temptations to the hardy and stronger people inhabiting the latter. The people living in Central Asia have invaded in the past the plains of India, of China, and of Europe chiefly, because of the rich agricultural lands. Their invasions were facilitated by the ease of movement either through mountain passes, as in the case of India and China, or through level plains, as in the case of northern Europe through Russia. These invasions have wrought changes of far-reaching importance in the history of the world.

On account of these invasions there is a considerable amount of intermingling of races and cultures in the plains. The purity of race which marks the isolated mountainous areas is never to be found in the plains. As ideas and people travel easily from one end of the plains to the other, the language, social organisation and cultures of the people in the plains are always in the melting pot, never fixed.

Rich agricultural lands and accessibility are, thus, the two main factors influencing life in the plains.

CHAPTER XIII

# RELIEF BUILDING AGENTS

PROC SS AT WORK—ICE—WATER—WIND—TYPES OF GLACIERS—LAW OF GLACIAL EROSION—GLACIAL TOPOGRAPHY—ICE AGES—RIVER VALLEYS—RIVER CAPTURE—RIVER VALLEY CYCLE—WATERFALLS—ACTION OF WAVES—SAND DUNES—LOESS—VULCANISM—EARTHQUAKES.

The irregularities of the earth's surface are the result of the action and interaction of a series of processes. These processes have been at work ever since the earth got its solid crust. The earth's crust is, therefore, the theatre of ceaseless activity which causes incessant change.

The processes at work on the earth are the following :—

(*i*) Denudation,

(*ii*) Diastrophism, resulting from the disturbed balance on the earth due to erosion, and

(*iii*) Vulcanism.

Diastrophism and Vulcanism may be said to *create* relief by raising or lowering masses of the earth's crust. Denudation, on the other hand, *destroys* relief by its tendency to smooth out the differences of elevation.

The process of denudation results from external forces which can all be traced to climate Diastrophism and Vulcanism, however, are due to internal forces. Denudation is sub-divided into :—

(*a*) Weathering or the disintegration of rocks.

(*b*) Erosion or the removal of rock.

Weathering prepares the rock for the more efficient work by erosion. Erosion and weathering both operate by chemical and mechanical means, and are aided in their work sometimes by organic processes, while throughout they are dominantly influenced by gravity. Man and beast remove the vegetation cover of the rocks sometimes and thereby expose them to a more effective work by denudation. Similarly insects bore holes into the earth's crust and thus help the work of denudation.

Erosion involves three stages : removal, transport and deposition. The American geographers call these three stages as degradation, and aggradation.

The agencies through which erosion does its work are several. These are : gravity, organisms, wind, glaciers, water, waves, tides, and ocean currents. These agencies are grouped under the following three main divisions :

(*i*) Ice, (*ii*) Water and (*iii*) Wind.

Rainfall gives place to snowfall when the temperature has reached a certain point. In higher latitudes and also in higher mountains, the precipitation is mostly in the form of snow. This snow melts during summer and gives rise to rivers. The rivers are the most active agents of erosion, but their source lies in the snow and ice that lies on mountain tops. This fact gives added importance to the study of ice as an agent of erosion.

## Glaciers and Glaciation.

Snow occurs largely in (1) high latitudes, and (2) high altitudes where there are low temperatures and where, therefore, rainfall gives place to snowfall.

When the snowfall is in excess of melting, a blanket of snow remains all the year round. The lines above which the snow remains permanently on the ground is called the *snowline*. This line indicates the average altitude above which more snow falls in winter than can melt in summer. It, however, never coincides with a fixed line of altitude, but is subject to such great daily or periodic fluctuations that it is impossible to speak of it as an unchangeable fixed line.

The level of the snowline varies greatly with latitude, with the amount of snowfall, with exposure to dry winds (which clear snow very quickly), and wi h topography (rugged slopes concentrating snow supply). The altitude of the snowline depends chiefly on latitude. At the equator the snowline occurs at a great altitude, at the poles it is almost of the sea level. Above this line snow goes on collecting in enourmous masses. There, is, however, a limit beyond which this accumulation cannot go on. This limit is determined by the atmospheric conditions which may cause melt'ng and evaporation, and the steepness of the mountain which may cause avalanches. Thus the word 'snowline' necessarily gives the idea of movement of masses of snow and ice. It is through this movement beyond the snowline that snow once again attaias the form of water by melting.

The snow surface that lies above snowline is called the *snowfield*. It has been estimated by Chamberlian and Salisbury that there are not less than *a million cubic miles* of snow and ice, which, if all melted and returned to sea, would raise the level of the ocean by about 90 feet.

The following table* shows the extent of the most important areas of permanent ice and snow:—

| | |
|---|---|
| Around South pole | 13,000,000 km. |
| Greenland | 1,900,000 ,, |
| Spitzbergen | 56,000 ,, |
| Iceland | 13,470 ,, |
| Norway | 5,000 ,, |
| Alps | 3,800 ,, |
| Caucasus | 1,840 ,, |
| New Zealand | 1,000 ,, |

Since ice under pressure flows, large snow fields whose base is ice, contribute flowing ice. Such flowing ice is called a *glacier*. The ice in the glacier is converted from the snow by pressure as well as by refrozen moisture. The snow which falls on the mountain peaks is fine and dry. In summer a little surface snow melts. The water thus formed trickles down deeper. When it meets the colder snow of the deeper layer, it freezes again and cements together some of the ice crystals that have been formed by pressure of the snow above. Part of the air between the snow particles is driven out and a transition, called 'firn-snow or neve' thus arises. Under the increasing pressure of fresh layers of snow, firnsnow becomes the firn-ice, finally hardening into solid glacier ice. Pressure and refreezing both help in the formation of ice. This ice begins to move owing to gravity and glaciers are thus formed.

The discovery that the glaciers moved was made by a Swiss, named Louis Agassiz, in 1834. Until then people had believed that glaciers were stationary. To prove the motion of a glacier Agassiz drove stakes in the ice, side by side, in straight lines across the entire breadth of the glacier. After a time it was seen that the stakes formed a curved line bending towards the valley. It was seen from this that the ice moved. It was also seen that the ice in the middle of the glacier moved more rapidly than the ice at the sides. Another point about the movement of the glaciers noticed was that the ice on the surface of glacier moves more quickly than the ice underneath, for the stakes driven deeper into the ice bent forward after some time. The glacier may, therefore, be called a 'river of ice.'

The ice of the glacier is granular and plastic. It tends to stretch or tear under stress. The surface of the glacier is, therefore, marked by fissures in the ice. These fissures are known as *crevasses* whose zone runs across the width of the glacier. These fissures are very dangerous to mountaineers. The crevasses are usually narrow and shallow. They occur anywhere where the ice is stretched due to the convex slope of the underlying rock.

*Passange: *Landschaftkunde*, Vol. III.

Another type of fissure that occurs in the glacial ice is called '*bergschrund*'. A bergschrund occurs near the head of the glacier when the ice is torn off from the steep rocks to which it is attached.

Besides these fissures the glacial surface is marked by *shearing planes*, or layers of distinct types of ice. Movements of the glacier take place along the shearing planes.

In Greenland, the glaciers are constituted of an upper portion of relatively clear morainless ice, and a lower part which is heavily charged with morainic material. In many cases, the upper clearer half overhangs the debris-choked basal portion, as if the movement forward of the former were greater than the latter. This feature is specially noticeable at the snout, though it is often to be seen as well in the adjoining borders for some distance upstream from the terminus, where actual cleaving can be seen to be taking place. The upper layers are moving differentially from the lower ones. They are in many cases being thrust forward as a unit over the more resistant basal layers. The basal layers display thrust-planes and drag-folds.

The Altai-Pamir Expedition by Russians and Germans in 1928 discovered the longest glacier in the world *outside the polar regions in Pamir. This great ice stream*, which has a length of 48 miles, was named the Fedchenko Glacier. It is located just to the east of and parallel with the crest of the Seltau Range. Its closest rivals are the Siachen Glacier (45 miles) and the Hispar glacier (38 miles) in the Karakoram, and the Inylchek Glacier in the Thien Shan.

There are four types of glaciers :—

(1) Valley glaciers. (2) Piedmont glaciers. (3) Ice Caps, and (4) Continental glaciers. Of these only the first has been studied to some extent.

## Valley Glacier

The Valley glacier is a glacier in a valley, down which it flows. A valley glacier is also known as an Alpine Glacier. The valley glaciers radiate outwards from the mountain snowfields, from which they move the snow outward and downward to a warmer climate, where the ice disappears by melting.

The supply of snow in valley glaciers comes from the steeper slopes, from the sky as direct snowfall, and large amounts are also blown into the valley by the winds which sweep over the snowfields. The sources of supply in a valley glacier are, thus : (*a*) direct snowfall, (*b*) avalanching from the valley slopes and (*c*) the indrift of windblown snow.

A valley glacier consists of a broad reservoir, from which a tongue of ice protrudes down the valley to some distance. At its

front the glacier has, normally, a relatively steep slope due to melting, and is not at all related to the slope of the valley bottom. The slope of the valley glacier varies greatly : some glaciers have a very gentle slope, while others are so steeply inclined that it seems a wonder that they are able to maintain themselves. This last type sometimes slides out of its valley.

The valley glaciers are divided into two classes ; the Transverse Glacier and Longitudinal Glacier. The transverse Glacier is one that flows down a valley at right angle to the range. The Longitudinal Glacier is that which occupies a trough between the ranges of mountains. The Rongbruk Glacier in the Himalayas is an example of a Transverse Glacier. This glacier is about 12 miles long. Its snout is at an altitude of nearly 16,500 feet. The Kangshing Glacier on the northern side of the Makalu in the Himalayas is an example of a Longitudinal Glacier. It is about 12 miles long, and the snout is at 14,600 feet above sea level.

There is much difference in the rate of motion of valley glaciers. Some of the smallest are almost 'motionless' ; while large glaciers move at the rate of several feet a day. The rate of motion increases from the margin towards the centre. Thus in the glacier of Mer de Glass in Switzerland the rate of motion at the margin is from 13 to 19¼ inches and in the centre from 20 to 27 inches *per day.* Sommervell and Odell found the rate of flow of the East Rongbuk Glacier in the Everest region to be only about 5 inches per day. Their observations gave a speed of 3 to 5 inches at the sides and 8 to 12 inches in the middle. The most rapidly moving glaciers are those of Greenland where some of them record a speed of 60 feet a day. The rate of motion varies with the supply. It also varies with the slope, steeper slopes have greater speed. There is also a variation with the temperature, the fastest motion being near the freezing point. Hence there is a greater motion in summer than in winter. The motion increases also when the valley walls come closer. The presence of debris tends to retard the motion. Motion is also retarded by friction against the rocky channel. In short, we can say that the movement of the glaciers is governed by stress and temperature differences.

There is a fluctuation in the ice front, *i.e.*, the snout, according to the ice supply which varies according to climate from season to season and year to year. At the present time there seems to be a general condition of wastage, and ice fronts are generally in recession, though prior to 1858 there were advances. Even during periods of general recession, individual glaciers may advance. The retreat of the glacier front does not mean that the ice moves backwards, but only that *the glacier does not reach the old limit*, owing to the decreased snowfall at the source. It has been seen that all glaciers recede simultaneously

and again advance simultaneously. It has been concluded from this that the force governing this simultaneous change lies outside the earth.

## Glacial Moraine

A glacier is a mixture of ice and the rock material which has fallen into it. In the case of the valley glaciers, the rock material is washed on to them from the sides while the glacier ice is accumulating. The valley glacier may have, therefore, rock material scattered through it from top to bottom. As the glacier moves, the rock material frozen into it moves with it and forms at the bottom an efficient erosive tool. The effect of the glacier armed with sand, gravel and boulders moving over rocks is like the effect of sand paper on furniture that is being polished. The sharp gravel and boulders scratch the rock surface over which the glacier moves. Where the glaciers move over soft rocks or loose rocks they pick up great quantities of debris. After the glacier has melted and deposited its load of rock, it is found that the rock material ranges from big boulders of 40 to 50 feet in diameter to small particles of sand and clay all mixed together. The rock material that has been handled by glaciers is called *drift*. Much of the glacial drift is called *boulder-clay*, because it consists of boulders in the midst of clay, and is heterogeneous in size. The other characteristics of the glacial drift are the absence of sorting and stratification, and the presence of flattened and scratched boulders.

Rock material is supplied to glaciers in several ways. Some is blown in by the wind, still more falls from the valley walls due to weathering; while far greater quantities come with the avalanches. To this supply the glacier adds from its bed. Some of the fragments in the bed are plucked loose by ice, and some are ground off by scouring. Unlike other agents of relief building, ice carries rock fragments irrespective of their size.

Owing to the nature of source, the debris in a valley glacier is carried mainly (*a*) near the bottom, (*b*) at or near the top and (*c*) some between the top and bottom incorporated in ice when it was formed out of snow. The debris at the top is specially abundant as it falls there from the wind and the valley sides. The bottom is a zone of abundant debris due to scouring and removal of loosened rock.

## Glacial Erosion

The erosive work of the glaciers has not yet been fully studied. There are several difficulties in doing it. In the first place, this work is confined mostly to inaccessible mountainous regions; and in the second place, the surface of erosion is generally hidden from view owing to the ice cover of several thousand feet in thick-

ness. The present conclusions about glacial erosion are based upon the surfaces exposed by the glaciers that have receded. The most useful field of glacial study has been provided by plains or low areas that were covered by glaciers in the recent glacial age in Europe and America.

Two things must be borne in mind about glacial erosion to place it in proper perspective. Firstly, that the glacial erosion affects, comparatively, only a very small part of the earth's surface. Secondly, that it is confined to certain periods and is not continuous.

Some writers have assigned only negligible part to the work of erosion by glacier (*e.g.*, Helm in 1885). Others have exaggerated it considerably (*e.g.*, Hess in 1904). One school considers the glaciers as the protector of the crust against erosion. The other school considers the whole glacier to be a powerful agent of erosion.

The evidences of glacial erosion (rounded, polished rocks, etc.) are unequally distributed over the glacial basin. This shows that while the glacier really erodes in one part, it protects the crust in another. Generally speaking the traces of erosion are rare where the glacier slopes. Here the dominant work is that of the under-glacier torrents, especially in the case of the glacial front. These torrents cut narrow and limited furrows. These are very numerous at the foot of the gradients. The erosion here is real but extends longitudinally.

There is a tendency for the glacier to enlarge its bed by lateral entrenchment. This gives a hummocky character to glacial basins.

Plucking or quarrying of the rock material is one of the most important methods of glacial erosion. But like all other liquids ice cannot but erode by abrasion or rubbing. The conditions of this erosion are, however, different from those of water, for (i) the speed* of the glacier is insignificant in comparison with that of water; (ii) its depth is considerable; and (iii) its adherence to the bed is not complete.

Speed, thickness, and adherence vary with slope; but the relation is not direct except for speed. Greatest thickness is found in more level parts. The thickness and adherence are the least at the gradients or slopes. It is also at the slopes that the cravasses appear in the glacier and reduce the pressure on the rock which is also done by the greater speed.

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*The maximum speed in the Alps is that of the Rohne Glacier (Mer de Glace) with 97 meters per year. The depth of the Glacier of Aletsch is more than 500 metres. Vallot has proved the empty space between the rock and the ice in the case of Mer de Glace.

The law of glacial erosion, as defined by De Martone, is as follows:—

*If the slope of the glacier varies, as it does, the erosion of the bed will attain its maximum below and above the ruptures in the glacier.*

Naturally the erosion by rubbing decreases towards and stops at the 'front' of the glacier. Fig. 115 below explains the significance of this law. The diagram shows that the greatest erosion is in parts where there is a depression behind the converse slope.

The erosion by moving ice is not the only factor in affecting the bed; the action of underneath water is also important. This has been shown by Brunhes.

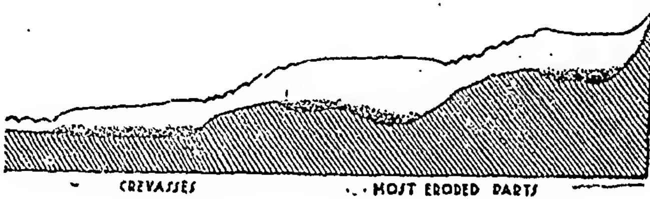



Fig. 115 Glacial Erosion.

## Glacial Deposition

The rock material carried by the glacier is deposited as soon as the ice begins to melt and the glacier terminates. The matter that is deposited at the end of a valley glacier is in the form of a ridge and is called *terminal moraine.* A terminal moraine may be about 100 to 300 feet high. Each time a glacier retreats, it deposits a fresh terminal moraine a little distance behind the first one. When the glacial retreat is not in the same direction but is irregular, a series of interlocking terminal moraines are formed there. The depressions between the ridges are often filled by lakes. If the glacier advances again over the terminal moraines it picks up the material composing the ridges and spreads it on the ground.

The material that is deposited at the sides of the glacier is called the *lateral moraine.* The lateral moraine consists generally of a single ridge rising to several hundred feet. When two glaciers join, their lateral moraines also join near the junction of the glaciers. Such joining moraines are called *medial moraines.*

The rock material deposited at the base of the glacier away from the terminal and the lateral moraines is called the *ground moraine.* As the rock load of the glacier is not uniformly distributed in the glacial ice, the deposit of ground moraine is thick in some places and shallow in others. The topography of the surface on which the

ground moraine is deposited determines the topography of the ground moraine itself. If the ground moraine is formed on a level surface, low hills arise where the rock material deposited is thick, and depressions where the deposit is shallow. These low hills are called *drumlins** and are only 50 to 60 feet high. If, however, the ground moraine is deposited in a rough topography, the valleys are filled by the moraine and the tops of the hills smoothed. When the glacier is moving across the valleys, the opening of the valley is blocked and lakes are formed.

Ground moraine assumes other forms also, *e.g.*, long, winding low ridges known as *eskers* kettle holes occur where ice pieces, were buried in the glacial drift which sags on the ice melting. The raised portion still left by the side of the hole is called 'kame.' The kames consist generally of material which is water transported.

The glacial streams can bring out of ice a volume of sediment which cannot be transported down the slopes of the valley. Consequently deposition commences and an *alluvial fan* is started with the apex at the ice tunnel. Over this fan the stream spreads, as in a river delta, through a multitude of distributaries. With their smaller volume the distributaries are the seats of still more deposit. Such a deposit, (also known as outwash gravel plain or valley train.) may spread over the valley bottom from side to side and accumulate to a considerable depth. It is stratified. The gravel is coarsest near the glacier, and it may grade down to a sandplain.

Very often the alluvial fan grows upward over the terminus of the glacier, burying the ice, specially where it has reached stagnation. Later, melting of the buried ice gives rise to pits, hollows and kettle-shaped depressions in the outwash gravel plain.

At the margins of valley and piedmont glaciers small lakes are sometimes held in between the ice and the land.

The valleys that have been occupied by glaciers show many distinctive signs. Many of the pebbles and boulders that were left by the glacier are polished and straightened by the attrition to which they have been subjected, as they have been ground against one another or against the valley bed. The rocks of the valley bed and sides are likewise polished and grooved.

## Erosional Forms

The above are the depositional forms produced by glaciation. There are certain erosional forms also that are characteristic of glaciers. The most important of these erosional forms are the following :—

*Also known as "basket of egg" topography.

(*a*) Cirques, (*b*) U-Shaped Valleys, (*c*) Hanging Valleys, and (*d*) Sheep rock.

Fig. 116. An Alpine Glacier. Note the narrow dark Moraine in it towards left.

(*a*) *Cirques.* Sometimes hollows are carved out at the side of a mountain by glacial ice cutting directly downward. Such hollows are somewhat circular and open at one end. At the opening of the cirque the slope is backward towards the head of the valley. Steep mountain walls rise on all sides except the opening of this depression. These amphitheatre-like depressions are called cirques. Other names given to the cirque are Cwm, corrie, etc.

The small patches of snow which lodge themselves here and there on the side of a steep mountain during winter melt in summer. The melted snow fills the crevices in the underlying rock. At night the moisture in the crevices freezes and breaks asunder the rock. In course of time this weathering produces a niche in which the snow settles down permanently and goes on widening and deepening them. Such are the beginnings of cirques.

Meltwater plays an important part in the headward erosion of cirque glaciers. In the parts of head walls exposed to the atmosphere, changes of temperature frequently cross the freezing point and so permit frost shattering to occur. Beneath the ice provided temperatures are below freezing point, meltwater has only to reach the rock face to permit similar shattering to take place at considerable depths. The two actions probably combine to sap head walls and to produce the features that characterize the deeper cirques.

When two cirques situated at the same height on opposite sides of a mountain go on widening, the wall separating them finally gives way. The opening formed across a mountain by such glacial piercing is called a *col*. When several cirques erode concentrically, spreading out towards one another round a common height, they produce *horns* which are three or four-sided pyramids. The famous Alpine mountain, the Matterhorn, is the example of a horn.

(b) *U-shaped Valley*. Unlike the river a glacier cannot dig a new valley. It can only widen a V-shaped river valley, converting it into the U-shaped glacial valley. Such valleys are characteristic of glacial erosion. The valley glaciers, while moving down mountain valleys, scour the irregularities formed by streams and thus change the narrow-bottomed valleys to U-shaped valleys. There are three things which mark out a U-shaped valley :—

(i) a broad floor : Sometimes lakes occupy the over-deepened hollows in the valley floor,

(ii) Steep sides,

(iii) Absence of minor bends.

(c) *Hanging Valleys*. The valley glaciers scour their valleys much deeper than the rivers left them. The main glacier scours more deeply than the smaller glaciers filling the tributary valleys. The result is that when the glacier disappears by melting, the tributary valleys are found situated at a considerable height above the main valleys. These tributary valleys are called hanging valleys.

(d) *Sheep Rocks* (Roches Moutonnees.) A glacier does not avoid obstacles. It flows over them and scours them. The side from which the glacier rides up the rock is made gently sloping, while

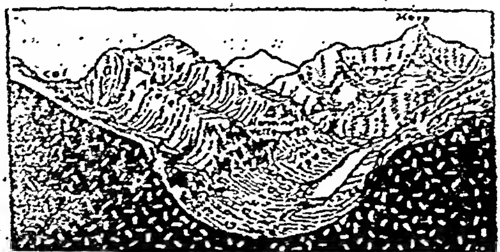


Fig. 117. Glacial Topography.

[Beginning from the left, note the positions of col, Arete, Hanging Valely, Cirque, Horn and Trough.]

the opposite side is made steep by it due to greater scouring. In the Alps where the glaciers have passed through valleys composed of dolomite, they have scoured the small knobs leaving conspicuous

small oval hillocks. These hillocks look like sheep, when looked at from a distance. The name given to them is, therefore, sheep rocks.

At the crest of the lee declivity, tension is introduced and the melting point of ice is raised. The interior of a glacier is at the pressure temperature melting point. A sudden diminution of pressure should result in a firming of the ice and its freezing adherence to the rock. Where clear ice is in direct contact with the bed rock, the measure of the adherence must be at least that of the tensional strength of ice, which is about seven tons to the square foot. A quarrying force of such dimensions would produce the steep, hackled effect characteristic of the lee sides of sheep rocks.*

Forms of the roches moutonnees vary. All variations of form are possible to roches moutonnees, from woolsack and half cylindrical swellings, to round, balloon-like knobs.

Roches moutonnee landscapes have a wide distribution.

*Rock Bastion.* Where tributary glaciers join main glaciers, the opposite wall is cut as in steps. These steps are called Rock Bastions.

*Fj rd* (Fiord). In some parts of Scandinavia, Scotland and Alaska lying in the Temperate zone, long arms of the sea are a common feature along the coasts. Three things are remarkable in the fiords : (i) the great depth of the water, (ii) separated from the sea by a sill or the shallow water between the sea and the deeper part, and ii) the steep walls bordering the fiord. It is believed that the fiords are river valleys on plateau escarpments deepened by past glaciers. It is known that a glacier would go on cutting even below sea level on reaching the sea. Ice does not float in water unless seven-eighths of its volume is sunk under water. Such a condition is not easy to find on a shallow coast. The glacier is, therefore, in constant touch with the ground and goes on eroding it until a change in the clima'e melts it down. The deep scouring behind the sill in the case of the fiord is a peculiarity of glacial erosion and is noticed in the case of the cirque also.

## Other Glaciers

The other types of glaciers, piedmont, ice-cap and continental, have not been much studied and our knowledge about them is scanty. The significance of the continental glaciers, like that of Greenland, lies in the fact that they are a source of *icebergs*.

*Drumlins also sometimes have a steep steep. In their case, however, the steep slope faces the direction from which the ice moves. In the sheep rock the steep slope is in the direction to which the ice moves.

### Ice Ages

Louis Agassiz was one of the first to prove (in 1840) that ice once extended over greater parts of the earth's surface. The geologists have proved the existence of at least two ice ages; the carboniferous ice age and the Pleistocene ice age, during the past. The Pleistocene ice age, being the most recent, is the best known of them all. During this period vast areas of Europe and North America were covered by a thick ice sheet. It is believed that from Finland and New York the last ice sheet retreated only about 10,000 years ago. Proof is available that during an ice age the ice sheet advances and then retreats. This has happened several times. The period between the advance and the retreat is known as the *interglacial stage*. We are living today in a period when the ice sheet has retreated. We do not know whether after some time it will not advance again. If it does, this period will be described later as an interglacial epoch. During the past the interglacial stages have lasted for thousands of years. For example, the period between the Riss and the Wurm glacial epochs is estimated to have been not less than 75,000 years.

The four last ice epochs forming part of the recent Pleistocene Ice Age in the Alps are named, in order of their age, as follows:—

1. Gunz (oldest).
2. Mindel.
3. Riss.
4. Wurm.

We are still in the dark about the origin of the glacial or the ice ages. It is, however, believed that they resulted from a combination of causes including cosmic phenomena, mountain building and volcanic eruptions.

Ice sheets of the glacial ages represent enormous amount of water. This water could have been drawn from the ocean only. Every spread of ice over the land necessarily leads to an appreciable sinking of sea level. When the ice melts, the water flows back to the ocean and the sea level rises on. This means that the ice ages have been responsible for a considerable amount of change on the earth's surface.

### Rivers and River Valleys

A river is a natural drainage line on the land. It is the means of the disposal of the surplus water, and its movement depends upon the pull of gravity, by which the liquid water, is being drawn toward the earth's centre, seeks the point nearest the centre that is most accessible. It flows, therefore, down-grade: *i. e.*, in the direction of the slope of the ground. In short, slope and water produce a river.

While running downgrade it transports a vast quantity of rock material; some in solution, some in suspension, and some dragged along its bed. By the movement of water, and largely by the use of the transported material as scouring agents, valleys are cut in the land. Rivers are the most potent agencies for carving out relief from the land surface and for the removal of the debris.

There are two points that are worthy of note about a river as an agent of relief building. The first is that the river has *water*. The second is that this water *flows*. These points may not appear to be important at first sight. But they are the basis of the whole of the development of a river valley.

Water is fluid which contains some corrosive gases like carbon dioxide. Because it is fluid, water can reach with its corrosive gases, crevices and joints in rocks where other agents cannot reach. The corrosive gases dissolve rock particles. The loss caused in dissolution makes the remaining rock particles loose and, therefore, ready to be removed. A great deal of the denudation of rocks is thus due to the fluidity and chemical nature of the river water.

The flowing water of the river transports rock material both as a solution* and as debris. The finer part of the debris is carried suspended in water; while the coarser part is dragged along. Dragging plays a very important part in rock denudation. The dragged parts of the debris collide among themselves as well as with rocks that are yet solid in the river course and cause widespread breaking. The dragging force is very important in the development of a river valley, because even a slight increase in the amount and the speed of the flowing water increases this force tremendously. The transporting power of the river rises to the sixth power of the velocity of the stream. Thus, if a stream flowing with a given velocity can move stone pieces weighing one pound each, by doubling its velocity stone boulders weighing sixty-four pounds each can be transported. The increase is, however, less if the debris is mixed. It rises then only to the third or the fourth power. But the tendency of the running water is always to sort out the material it transports. So that the increase is to the higher power generally.

The reverse is also true. Even a slight decrease in the speed and volume of flowing water forces the river to drop most of its load. Any obstacle to the flow results in deposition. Cutting and depositing which produce a river valley are, therefore, inseparable from the flowing water.

The river water does the double work of :—

*It is estimated that on the average about 8000 million tons of rock waste are removed from lands to the sea every year. Of this about 30% is carried away in solution.

(i) *Corrosion* (or degradation by mechanical means through dragging of the rock material on unconsolidated rock) and (ii) *Corrosion* (or chemical weathering of solid rock). The mechanical or *corrosive* work is primarily dependent upon the sediment load which the river current drags along its bed. It is also greatly influenced by the volume and velocity of the water and the nature of the rock. The chemical or *corrosive* work, on the other hand, depends upon (i) the *volume* and composition of water, and (ii the nature of the rock. This work is slow, for even in such a soluble rock as limestone the rate of excavation by the process of *corrosion* is slow.

The river erosion consists of the cutting of rock by weathering and chemical means, and the transportation and deposition of the eroded rock material. It is in this way that a river makes a valley for itself. The river erosion is not, however, uniform either from the point of view of time or of place, owing to the eddies in water and the differences in rocks. River work suffers also on account of seasonal change of water supply.

A balanced flow is the object of the river. Therefore, valley cutting is limited by the *baselevel* or grade (gradient or slope) of the river. At no point in its course can the stream cut its valley much below the level of its mouth. This level for the river is its *baselevel*. The ocean surface is the great baselevel, but individual streams may have *temporary baselevels* such as a lake or the river to which they are a tributary.

Valley-cutting below the baselevel is not practical, since the water must have a slope over which to flow and to transport its sediment load. The sea is the lowest point in relation to the source of the river. The gradient between the source and the sea gives the river water the power to flow. As soon as the river has reached the sea, or the grade, this power to flow stops. The lowest slope over which a river can transport its sediment load may be called its *grade* or gradient. This grade is a curve, flattest near the mouth where the volume of water is the greatest, but increasing in steepness towards the head waters where the volume of water is the least. By its erosive work a stream tends towards the attainment of a perfect grade. The grade is, however, not to be considered a definite curve that, once established, is fixed for ever. It changes to meet the newly developed conditions owing to degradation and aggradation.

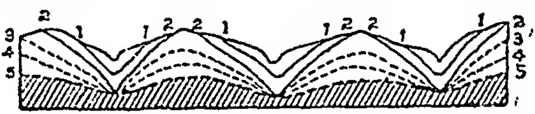
The notion of the baselevel was defined by Powell in his report on the Grand Canyon of Colorado in 1873. Before, the Dausse had introduced the idea of the Profile of Equilibrium. The baselevel curves of the rivers are hyperbolic curves.

The sea level is the most permanent of the baselevels on the earth. But there are limits to its influence. In the first place, about 42 million sq. km. of the continents, that is, 27 p. c. of the continental area, is such as does not carry its drainage to the sea. Such areas are the ice-covered polar regions, basins of inland drainage and desert areas completely devoid of drainage. Among the basins of inland drainage may be mentioned the Caspian sea which is 26 metres *below* sea level, and the Aral sea which is 73 metr s above sea level. In Central Asia, North America and the Andes, basins of inland drainage are situated several thousand feet above sea level.

The sea level itself is, however, not stationary in the long run. The large deposits of snow over Europe and America during the ice ages must have drawn the requisite water from the ocean and thus lowered the sea level. Besides, the tectonic movements also affect the sea level by raising or lowering the land.

As the perfect grade is approached, cutting decreases considerably. During this stage weathering is the main factor in valley formation. The sides waste away, the valley broadens and the slopes lose their steepness.

The following diagram shows how the grade is attained :—




[*After De Martonne.*

Fig. 118. Valley Formation.

(1-2 show the stage where the downward cutting is most marked ; 3-4-5 show where the lateral or side cutting is most marked : 5 shows the baselevel.)

The river is assisted in its work of carving out a valley by other agents as well. This assistance is most noticeable along the sides of the river valley. Rain water soaks through some of the rocks forming the valley sides. Apart from loosening the rock particles it also makes them slippery. Encouraged by the force of gravitation along the steeper slopes of the valley the rock particles slip down into the river valley from where they are removed by the river. This process is known as '*solifluction*'. Landslides from the valley sides are the result of this process. Solifluction attacks rocks which could not be reached by the river in the ordinary process. The decay of the valley sides in this way widens the river valley.

As the valley widens, new rivers are born to drain the water from the widened parts. These rivers are tributaries to the main river, but their work is essentially the same, cutting and depositing. By bringing more water and more debris to the main river they increase the cutting capacity of the main river. A further expansion of the river basin takes place in this way.

Some of the tributaries are able to cut back into areas which are in the basin of another river altogether. Because of their greater cutting capacity they capture the drainage of this neighbouring basin and help still further in the expansion of the valley and the drainage basin of the river to which it is tributary.

Thus, cutting as a process in the formation of a river valley implies three things : (i) deepening of the river valley, (ii) lengthening of the river valley; and (iii) widening of the river basin.

During the process of cutting by the river rocks of different resistance are encountered by it. The softer rocks yield easily and let the river flow on. The harder rocks, however, resist and deflect the flow of the river for a time. That is the reason why no river has a straight course. All rivers have a zigzag course.

If the hard rock appears in the path of the river stream, so that the river flow cannot be deflected being bounded by the Valley Walls, the flow is broken by a waterfall or a rapid so long as the rock obstacle is not removed by cutting.

Deposition of the material being transported by the river takes place whenever and wherever the speed of the flow slackens for some reason or the other. Two outstanding factors in this slackening are: (*a*) the approach to the baselevel, *i. e.*, decline in the slope of tne river bed; and (*b*) decline in the volume of water in relation to the load carried by the river. This latter condition may occur due to the decreased supply of water to the river, or to the increased supply or load. In both cases, the river is unable to transport all the material that it is carrying.

The larger pieces of the rock and coarser material in the load are the first to be dropped. The finer material held suspended or in solution is carried farther down. But whenever the water supply increases due to floods the dropped material is once again picked up and transported further. The unfinished worked of the river is thus completed during floods. The big rock pieces which cannot be brought into the main current of the stream are generally buried under deposits of finer material which drops down from the comparatively stagnant or slow-moving water along the margins. Such a deposition makes the beginnings of a *flood plain*. The river water reaches this plain only during the floods and then leaves there a considerable deposit. The flood plain begins in the middle section of the river valley where the slope is gentle enough to lower the speed of the river flow. It is broader in the lower section of the valley where, besides there being a gentler slope, there is a large amount of load in the river. Deposits of material are, therefore, extensive in the lower section of the valley.

In the flood plain, specially in the flood plain of the lower section of the valley, changes in the course of the river are frequent. Sometimes the river course shifts several miles overnight. Such rapid and frequent changes in the course are explained by the large amount of finer load in the water which is deposited quickly even at the slightest obstacle. During the dry season such heavily loaded rivers deposit the load in mid-channel and develop an intricate course due to the sand ridges separating the water. Such a course is known as "braided". The Ganga provides an important example.

Another characteristic feature of the flood plain is the presence of 'levees' or 'banks' on both sides of the river stream. These levees may be sometimes ten or even twenty feet high. The origin of these levees is also connected with the large amount of load in the water. The current of the stream is usually in the middle. The load in the current of the stream is transported easily. But the load in the water at the margins of the current is not transported so easily, for the flow of water there is not quite strong. Besides, the marginal water is constantly in friction with the land that lies in the margins. The coarser particles that are held suspended in the marginal water, therefore, drop down. This is the beginning of the levee. The process goes on repeating itself until the levees are high enough to confine the river channel between them.

The levees are not permanent, however. On account of river meanders they may be undercut by the stream and thus collapse. They may also be attacked and removed by the stream during floods. For it must be remembered that the levees encourage the silting of the river channel confined between them. The material that would have been spread over the flood plain, if the levees had not been there, is forced on to the main channel which finds it too much to carry, especially during floods when it is choked with load. When the channel is silted the river crosses the levees and makes a new course in the flood plain, a large part of it is then flooded.

The artificial walls built along the Mississippi river to check floods have proved to be worse than futile on account of this silting up of the channel. About hundred years ago only four-feet high levees were enough along this river. Now even twenty or thirty-feet high artificial levees are not enough to check the floods. The result of the artificial levees is that the river bed is raised considerably above the surrounding areas of the flood plain. The levees have, therefore, to be raised frequently to keep the channel confined. Once the levees give way to the river flood, large areas are submerged under water. The loss of life and property is huge in such cases. Raising of walls along the river is no way to control floods. Floods can be controlled only by the controlling supply of water in the river. This can be done by (i) planting forests in the upper sections of the

rivers, (ii) dredging and straightening of the river courses; and (iii) by building reservoirs for storing flood water at suitable spots in the river valley.

Beyond the flood plain the river still carries a considerable load. But here the load consists of the finest material or the dissolved material This material congeals and precipitates when the fresh water of the river meets the saline water of the sea. The formation of the delta is thus begun. The delta emerges out of the sea, because the river is continually dumping thousands of tons of material into the sea. The sea is thus forced back. The process of delta formation is similar to the formation of an embankment for the railway. To form the embankment, earth is dumped into the depression. The river does the same thing to form its delta.

## River systems

When rain-water falls on an elevated land it seeks its own level which is the sea. In attempting to reach the sea, it flows down the slope. Gradually it makes a permanent channel for it. As has been seen above, this channel finally develops into the river valley to which a river confines itself.

The course of any particular channel is determined by natural irregularities of the land surface. Originally when land arises from the sea. the river courses are *consequent* upon the topography that the running water meets. Such rivers are, therefore, called the *consequent streams*. But during the period when its valley develops and passes through the different stages the stream may undergo very notable changes in position and depart very widely from the original consequent course. Such a river that has changed its original course is called a *subsequent stream* to distinguish it from the original consequent stream. The tributaries that develop to join a consequent stream are also called *subsequent streams*. The main causes which give rise to such changes in a stream course are :—

(1) *Straightening.* The original consequent course may be very irregular and roundabout. During the course of the development of the valley such a course will tend to be straightened up. Or, the original course may be straight, but with subsequent development meandering may be set up.

(2) *Adjustment to Rock Structure.* The original course is determined by topography and not by the rock structure. It may happen that a consequent stream is flowing on a resistant rock, while not far away there are much weaker beds. As the surface wastes away and a valley develops in the weaker beds, the original consequent course may be abandoned for a subsequent course along the weaker rock.

(3) *Shifting of Divides.* The headwater erosion by adjacent streams is unequal. This is because one stream may have an advantage over the other owing to (*i*) increased volume, (*ii*) lower base level, or (*iii*) weaker rock and may cut more quickly. The headwater erosion, therefore, not only reduces heights of divides but also causes them to shift horizontally.

When the flow of a river has established its grade, the force of the river is directed mainly to the widening of the valley, especially in its upper course. This widening is attained chiefly by the shifting of divides between the rivers. It is noticed that in a region where the geological structure is simple and horizontal, and the amount of rainfall is equal the shifting tends to make the slopes gentle on both sides of the divides. This tendency is known as Campbell's *Law of Equal Declivity.* This law says that "when slopes of unequal steepness occur on two sides of a Divide the more rapid reduction of the steeper slope will shift the dividing ridge toward the gentler slope, until it has been lowered and acquires a symmetrical cross-section."

In regions where the geological structure is complicated and beds have considerable dip, the divide will shift in the direction of the dip of the beds so that the cross-section of the ridge will remain asymmetrical, with unequal slopes on two sides. This is known as the *Law of Monoclinal Shifting.*

(4) *Stream Piracy and Diversion.* There are many ways in which this is brought about. If one stream finds conditions more favourable for development than another neighbouring stream, it may, by the extension of branches or of headwaters, cut back until it draws upon part of the water supply of the less favourably situated stream and finally diverts it to its own channel.

### Insequent and Obsequent streams

There are rivers in which no adjustment to rock structure takes place. This is either (*a*) because of widespread, flat-lying sediments ; or (*b*) because the stream develops in a large area of a massive formation, such as granite. Such rivers never have subsequent tributaries. This is because the adjustment is complete from the very beginning. They are called *insequent* rivers. The insequent stream pattern is often tree-like for which reason the drainage is said to be *dendritic.*

When, however, adjustment to inclined sedimentary beds results in subsequent tributaries flowing in opposite directions across the trend of the rock structure, the tributaries are called *'obsequent rivers*. They develop specially upon the escarpments of belted coastal plains.

The river systems group themselves into three types or patterns, dendritic, trellic and annular or radial. The commonest type that is developed where the rock structure does not interfere with the valley development is the *dendritic* or tree-like. In this pattern the main river looks like the trunk of a tree, while the tributary rivers present the appearance of branching out from this trunk. The dendritic type is first enlarged by the increasing number of tributaries, but as the cycle of erosion progresses, it is simplified by having a few tributaries of larger size.

The *trellic* pattern of river system develops where the rock strata of varying degrees of resistance dip at an angle, so that the more resistant beds come to the surface to form ridges which are separated by asymmetrical valleys. The drainage in such valleys is more or less parallel. It consists of long, straight valleys, following the arrangement of the rock strata.

Where the ridges are arranged round the margins of a dome the trellic pattern becomes curved and is called *annular*.

The following diagrams show the patterns of river systems :—

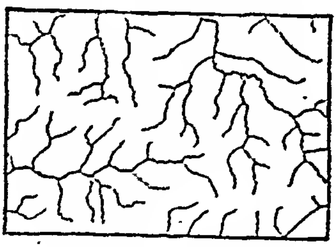


Fig. 119. Dendritic.

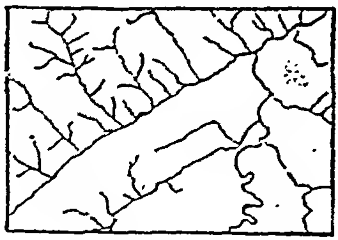


Fig. 120. Trellic.

## River Capture

Conquest of drainage is the most common law followed by running water. The river basin most favoured in slope, rainfall and nature of rock must enlarge itself at the expense of the less favourable.

Philippson, a German, was one of the first to draw attention to the general phenomena of river capture in 1886.

Anything that accelerates headwater erosion on the side of a divide, as compared with that on the other side, gives opportunity for the pushing back of the divide and the possible capture of headwater. Monoclinal shifting of divides, the presence of a resistant stratum across a stream, earth movements, glacial action, volcanic deposits and even avalanche deposits may be the causes of river acpture. Fig. 121 illustrates the principle of river capture.

A river capture always leaves behind the following evidence :—

(*i*) A Beheaded River that is too small for the size of the valley in which it is still flowing as a diminished stream. It is a 'misfit' river.

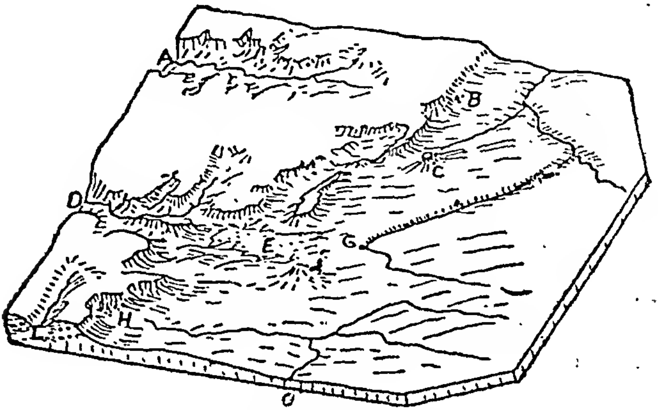



Fig. 121. In the diagram the river A is cutting towards the river B. As soon as the divide separating these two rivers has been cut sufficiently, the tributary waters of B will flow into A, and thus B will be captured by A. Part of another river D has already been captured at G.

(*ii*) An Air Gap takes the place of the dried up section of the river valley which lies between the beheaded river that is still flowing in its original course and the reversed river.

(*iii*) The Elbow of capture always marks the spot where the river capture has taken place. Generally, the capturing river approaches from the side. A bend like the bend of the elbow, therefore, occurs when slower stream passes on into the more active stream. In Fig. 121, G marks an elbow of capture.

Crosby* points out that although many instances of stream capture or piracy have been described, comparatively little has been written upon the methods by which it actually takes place. There are two prevalent theories concerning the final act of piracy. According to one theory, the final act takes place suddenly by overflow of the upper stream into the valley of the lower or captor stream. According to the other, the capture takes place underground by the lower stream before the lower valley is actually cut back into the upper valley. The first theory is the older, but undue importance has been attached to the second in recent years.

*I. B. Crosby, Journal of Geology, July and Aug., 1937.

Crosby recognises three distinct types: capture by (*i*) *headward erosion* which will eventually occur wherever adjacent streams are at markedly different levels and the tributaries of the lower are working back towards the upper stream; (*ii*) *planation capture*, a less common process due to the lateral cutting of one stream into the valley of another which may be about the same level; (*iii*) *subterranean capture* of surface streams, which is important in soluble rocks. The final act, however, of the first two types may occur underground if conditions are suitable.

Final act of capture only takes place underground in limestones, pervious sandstones, sand and gravel. In impervious or insoluble rocks igneous or metamorphic, as well as in shales and clays, which are more abundant, the final act is nearly always on the surface, and does not occur as the result of water that may seep through joints.

## Antecedent River

The work of the river is sometimes disturbed by the play of the internal forces of the earth. These forces raise the land. This rise is known as '*upwarping*'. The upwarping creates an obstacle in the path of the river which the river is forced to remove. The removal of this obstacle is done gradually with the increased power of cutting that the river acquires through the obstacle. In the first place the water flowing in the zone that is being uplifted begins to flow more rapidly due to increased gradient. This rapid flow cuts quickly into the rising portion of river course backward. Very often it happens that the raised portion in the path is removed as quickly as it rises. In the second place, the obstacle dams up the flow of the river in the upper course and forms a lake. The dammed up waters of the river attack the rising land from their side chemically and mechanically and this very soon the normal flow of the river is established. The main evidence of the disturbance created in the flow of the river by upwarping is the deep gorge that marks the spot of the disturbed flow. Other evidence occurs in the deposit of the finer silt of the river in the flood plain formed in the former lake portion of the river.

Such a river is called an '*antecedent river*' meaning that it existed before the upwarped land or mountain range came into existence.

An important example of such a river is to be seen in the Arun in Nepal.

The Arun rises on the northern slopes of Gosainthan, a peak of the Himalayas 26,000 feet high. Near Kharkung it flows through a gorge across a mountain called the Yo Ri, about 18000 feet high. Twelve miles above the gorge the river is flowing in a broad valley over the post-glacial spread of gravels. Traced downstream the valley remains open, but the river cuts gradually deeper

into the gravel lying in the bottom of the valley until at Kharkung, immediately before the gorge, the river is flowing 700-100 feet below the upper surface of the gravel. At this point the river plunges into the mountain side. The gorge of the river runs south for about four miles and then turns through a right angle and continues in that direction for another four miles before ending, as suddenly as it began, in a broad valley. This valley is also floored by post-glacial gravels.

The Yo Ri gorge is cut in hard gneiss. To the east of this gorge immediately there is a pass 'Kuyok' only 18·o feet high which consists of soft schists. The change from the relatively soft rocks of the Kuyok to hard resistant gneisses is abrupt. The close association of the Yo Ri gorge to the low pass of the Kuyok is interesting. If the original surface on which the Arun flowed were like the present one, then the river would have taken its course over the lower ground to west of Yo Ri which is now the Kuyok La. As this is not so, the Arun River must have firmly established its course before the development of the present relief. The Yo Ri and the Kuyok were not in existence there.

Such gorges occur in other rivers reaching India from beyond the Great Himalayan Range, *e. g.*, the Indus, the Sutlej and the Brahmaputra, etc.

## Rejuvenation

When upwarping takes place, the gradients of the rivers are increased. This increases the speed of river flow which leads to increased down-cutting by the river. The increased down-cutting is concentrated generally in the midstream where the river develops a new course. In this process part of the old flood plain and the old levees are left at some height above the new course of the river. These form the river terraces which the river water can no longer reach.

One of the most-marked results of rejuvenation is the deepening of river meanders. Such meanders are called 'incised meanders'. The meander loops in a rejuvenated river are gradually excavated into a continuous winding gorge. These winding gorges are the incised meanders.

The Grand Canyons of the Colorado river in the United States of America are a remarkable example of the gorge made by rivers on rejuvenation due to uplift. The Grand Canyon is locally about a mile deep and runs for a distance of more than 300 miles. It cuts across a plateau that was formed by the rise of a peneplain to a height of 6000 to 8000 feet above sea level.

## River Valley Cycle

W. M. Davis, an American, gave to the world the idea that land forms pass through a cycle of development. This idea is of fundamental importance in an interpretation of river valleys. The *geographical cycle* has been defined as "the period of time during which an uplifted land mass undergoes its transformations by the processes of land sculpture, ending in a low featureless plain".

Even though originally the idea of the cycle was applied only to river erosion, it has now been extended to all the forms of erosion like wind, water, and ice. The significance of the idea of the cycle of erosion is to give an ordered sequence through which the life-history of landscapes passes. We know the 'whence and whither' of land-forms. It is not assumed, however, that every cycle of erosion need necessarily run its full course. It may be interrupted at any stage. The cycle concept only emphasizes the fact that "the *initial* forms pass through a series of *sequential* forms to an *ultimate* form, which is recognised to be a *peneplain*." The recognition of the fact that eventually all relief is obliterated is the first principle of the cycle of erosion concept.

The uplift of new land provides the initial form and sets the erosive forces to work. These forces produce the ultimate form and complete the cycle. There have been so many interruptions in the past that it is difficult to find anywhere on earth the model peneplain.

The landscape that results from the cycle of erosion is, according to Davis, "the function of structure, process and stage." The nature and the arrangement of the rocks, the type of the agency of erosion, and the stage which has been reached in its work of relief-building by that agency, all combine to explain the type of landscape that is found in any part of the earth.

According to Davis, the river valleys can be divided into three broad classes on the basis of their stage of development. *Cutting* and *deposition* are the two essential features of valley development. But these features are not found in the same degree in every phase of valley development; one or the other feature may be more important. In one phase, cutting may be more important than deposition, while in another phase deposition may dominate. The three stages of river valleys are :—

(*i*) Youthful stage, in which cutting predominates ;

(*ii*) Mature stage, in which cutting and deposition balance ; and

(*iii*) Old stage, in which deposition is dominant.

The rain that falls on land runs down the slopes towards the sea. Where there is enough slope, it quickly finds some parts lower

than others, the run off tends to concentrate towards these parts. Along the lines where water concentrates there is excavation, and with excavation more water is concentrated there from the higher areas in the neighbourhood. As the water flows towards these channels, tributary channels are formed. A river system thus develops.

### Youthful Stage

As the run off from land proceeds, the channel ways are deepened. This is because the volume of water in the stream is greatest here, and also because this is the point where it can cut deepest. The lower portion of the stream is the part where the valley develops first. Accordingly at, and just above, the mouth of the main streams, valley cutting proceeds apace, as it does also at the mouths of tributaries that enter a cut channel. From these points the valley development extends *upstream* farther and farther, as the down-cutting in the lower portion gives the stream opportunity for excavation.

The young stream breaks through all the obstacles placed in its way in order to reach the bottom as quickly as possible It cuts in where its channel is the deepest. This down-cutting gives to the valley the characteristic V-form in a cross section. Where such rapid down-cutting is in progress, a gorge-form of valley necessarily results. The depth of the gorge will depend upon the elevation of the land surface above the baselevel, while the speed with which the gorge will be formed depends upon the volume and the velocity of water on the one hand, and the nature of the rock, on the other.

The gradient of the river in its middle course is not so steep as in the upper course where the gorge or V-shaped valley is formed. Consequently, the river flows more slowly, though still strong enough to undermine its banks. Where the river has to curve to avoid some obstacle that it cannot remove, it drops the transported debris on the inside of the curve. The river shallows, therefore, on the inside of the curve. The V-shaped valley is given a broader floor in this way. A broader V-form will also result if the rock be unconsolidated and lateral erosion (side-cutting), therefore, is more active.

Once the lower portion of a stream has reached baselevel, the gorge form wastes away slowly under the attack of rain wash and weathering. As the stream cuts down to the baselevel, the lower valley may broaden considerably while the gorge valley is developing farther upstream and in the headwaters.

In the earliest stages of drainage there are areas of poorly drained land and even of swamps. The divides are flat-topped and broad, and the distance between the well-defined channels is great. As the tributaries of the main stream cut back, and as secondary

tributaries develop from these, the flat-topped divides are eroded and narrowed. More and more of the surface, thus, has slopes down which the run off can flow. This extension of the tributaries is accomplished by cutting back at the upper portion. This is described as headwater erosion.

The river system is then passing out of the stage of youth. The condition is somewhat like that of a tree which may be broad and mature at trunk, while at the same time it sends out a number of fresh, young twigs from each of its branches.

The characteristics of youthful valleys are: the presence of (1) the gorge-form (2) waterfalls, (3) lakes, (4) poorly developed divides. Even a single one of these features is indicative of the youthful stage.

## Mature Stage

During the stage of maturity rapid down-cutting stops. The valley begins to widen by the more vigorous lateral-cutting of the walls. The slopes of the divides become gentler and their tops become narrower. The dividing ridges as a whole are lowered down. As a result of this, river-capture is a common feature. The drainage of several basins is thus integrated. With river capture, the upper basin is greatly dissected and a large amount of debris is deposited in the lower basin.

As the lateral cutting progresses, a definite belt of meanders starts in the river bed. The meanders form and reform due to the varying condition of the river flow. The meander belt widens and shifts down the course of the river. The meanders not only help the river in its side-cutting, but also help in the formation of the flood-plain of the river.

The first beginnings of a flood-plain are made by the accumulation of debris along the inside curve of a meander bend. From there the flood plain enlarges. Increasing deposition not only enlarges the flood-plain, but also raises its level. A time comes when the flood plain fills continuously the whole valley, even encroaching on the valley slopes. It then becomes the valley plain.

## Old Stage

The change from maturity to old age is marked by the gradual elimination of the structural control of relief. But the local resistant masses spared by some accident in denudation may still continue as "monadnocks." This stage of a river system is reached when all its rivers have reached the grade. Their flow becomes so sluggish that meandering is most marked. Their valley plain now becomes a low featureless plain.

In the above classification of river systems, there is no reference to the age as measured in years, but to the stage as measured by the amount of work done or still to be done to complete the cycle.

## Waterfalls

The existence of a waterfall as well as of a rapid depends upon the difference in the rocks forming the floor of a valley. If the valley floor consists of a uniform type of rock, the development of the valley is also uniform, and no waterfalls or rapids develop. If, on the other hand, the rocks differ in different parts of the valley the development is naturally not uniform. In the following diagrams three cases have been shown :—

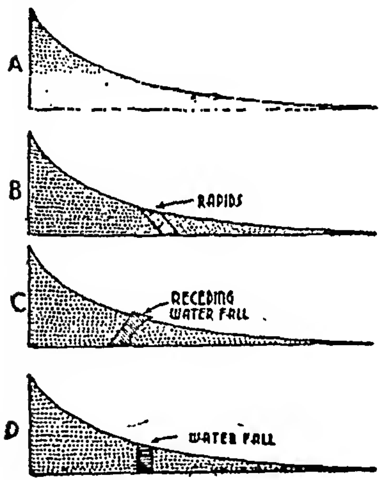



Fig. 122. Effect of rocks on river flow.

In A, uniformly soft rocks form the valley. There is no obstacle to river flow, and the slope of the river is, therefore, uniform throughout. In B, there occurs in the midst of the soft rock an area of hard rocks. The river is not able to cut this rock as quickly as the soft rock in the rest of the river valley. Rapids are, therefore, caused at the place where the river meets this hard rock. In C also hard rocks are met with, but their dip, in this case, is different from the dip in B where they dip gently down the stream. The softer rock is cut away more quickly than the hard rock lying in the course upstream. A steep gradient is created and the falling water excavates the soft rock lying in the course of the stream below the hard rock. The water that falls makes a 'plunge pool' below the resistant rock. Falling water produces a spray which reaches the soft rock forming the wall underneath the resistant rock. This spray causes the denudation of the wall. A portion of the resistant rock above the wall, therefore, becomes unsupported and overhangs. Ultimately, it breaks and falls down. The fall thus shifts its position upward. Another plunge pool is formed and the whole process is repeated. This receding of the waterfall backward in the valley produces a gorge, the down-end of which shows where the first waterfall was started. In the Victoria Falls on the Zambesi this gorge is 60 miles long. The gorge

continues to form so long as the resistant rock remains. In D, the hard rock dips vertically, so that there is no excavation under it. The waterfall that develops in such a case does not change its place.

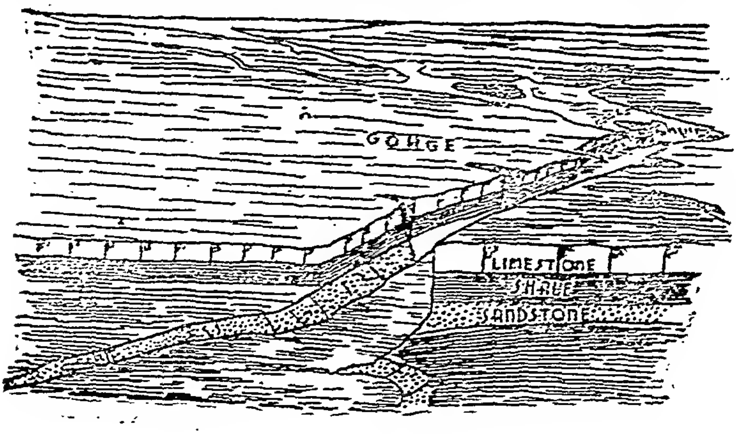
The disturbance in the normally uniform flow of water as caused by the exposure of a harder rock in the path of a river is known as a waterfall, cascade, cataract and rapid. A waterfall results when the resistant rock has a dip against that of the soft rock so that the wearing down of the soft rock quickly produces a great difference between the two sections of the river flow, one above the resistant rock and the other below it. This difference causes the river to fall.

A cascade results when there are a series of falls in quick succession.

When the dip of the resistant rock is in the same direction as that of the soft rock, a 'rapid' flow of the river results in the portion occupied by the resistant rock.

The name given to such a rapid is a cataract if the amount of water flowing is very large.

The Niagara Falls are the best example of a receding waterfall. These Falls are on the Niagara river which drains the Lake Erie. The Falls are about 160 feet high. The waterfall is divided into two sections by the Goat Island which occurs in the river just above the Falls. The wider run of the Falls (2800 ft.) is on the Canadian side. On the American side the extent is about 1000 feet. The Canadian side is known as the Horse-Shoe Falls, owing to its curved




[After Lyell

Fig. 123. Rock Structure of the Niagara Falls.

shape. The preceding diagram shows the rock structure of the Niagara Falls which are due to the rapid cutting of the soft shale underlying a hard limestone.

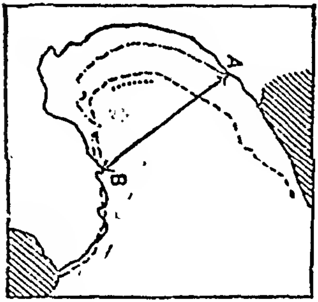



Fig. 124. Continuous line shows the position of the Falls in 1842, the middle line shows the position in 1875, and the innermost line is in 1905.

The Niagara Falls have migrated upstream from Leviston, a distance of about seven miles. The average rate of this migration has been about three feet per year*. The side diagram shows the retreat of the Falls from 1905.

Waterfalls are a peculiarity of (*i*) glaciated regions, (*ii*) margins of plateaus, (*iii*) newly formed lands, and (*iv*) areas of discordant rocks. In all such regions there are great and sudden changes in the levels which help the formation of waterfalls. The waterfalls are, however, a temporary phase in the relief building process of the earth. They disappear as soon as the drainage has adjusted itself to a grade.

## Mature Stage

The development of maturity of valley form is but a continuation of the processes outlined above. The lakes have been filled, the waterfalls have disappeared, and the river is approaching grade, by the headwater erosion the land is now provided with slopes down which the water may run. The divides are narrowed and the region is traversed by a complex network of valleys. Weathering and rain wash are the main elements in denudation at this stage. The main task of the stream now is the drainage of the land and the removal of the sediment turned over to them; though here and there, by swinging against their valley walls, they may be engaged in actual work of excavation by lateral erosion also.

While in this stage, the streams have nearly reached their grade. There are two sections, however, where the grade is still in the process of establishment. One of these sections is in the upper course, where the streams are still cutting their beds, and where the valleys may even be youthful with gorges and waterfalls. The other section is in the lower and middle course, where the stream may be engaged in raising a low grade, established earlier in the cycle. The stream may aggrade its lower course and build flood plains, as the sediment brought may be greater than the stream can carry away over the low

*This is the rate of retreat on the Canadian side. On the American side the Falls are receeding only 8 inches annually, as less water flows down there.

grade established during youth. Flood plains develop along a large part of the mature river, and over them the river forms meanders. The characteristics of the Mature stage are:—

(1) Flood plains and meandering streams; (2) moderately sloping valley sides; (3) a well-defined drainage system with many tributaries and definite divides; (4) a fairly well-established grade; and (5) the absence of waterfalls and lakes.

Side cutting through weathering broadens the valleys in this stage. Movement of soil from the slopes has been proved by Gotzinger who has shown that in the Wienerwald near Vienna, a displacement of 30 to 50 centimetres takes place in a slope of 5° to 30°.

## Old Stage

In the river valley development, youth is relatively rapid, maturity is longer, but old age is of almost infinite duration.

In this stage the valley slopes are worn down to even less relief than is found in maturity. The flow of water is retarded, so that considerable amount of water is lost by evaporation. The river volume, therefore, diminishes. The old rivers do not cut any more. It is only in their upper course that they tediously transport pebbles which are brought to them by other rivers. These pebbles are deposited by them in the middle of their course. There is also, therefore, a decrease in the sediment load, and that which is supplied is finer than in the earlier stages. The main difference between old age and maturity lies in the decreased valley slopes which finally result in a peneplain.

The old stage represents the stage when a river has fulfilled its task of reducing mountains and other elevations to sea level and thus to reach a state of equilibrium. Few rivers ever reach, however, this state of equilibrium, owing to their rejuvenation which may be brought about by any one of the numerous forces working on the earth s surface. A trifling uplift of the land, or an increased supply of rain due to climatic changes is enough to set the river working again with rejuvenated vigour.

This rejuvenation may suddenly put a stop to the existing cycle and may start a new one. The idea of a cycle (going back to the point of start as in the case of a wheel) in the river valley development lies in the fact that the river valley is not a permanent feature of the earth. It passes through various stages which are restarted with every rejuvenation. Every river starts from a youthful stage and passes through maturity to old age, if undisturbed. A rejuvenation takes it back to the youthful stage, which is the starting point of the river cycle.

The criticism levelled against Davis idea of a river valley cycle is twofold :—

(1) The word 'cycle' is not a proper word, because it implies reversal to the point of start.

(2) The description of the valley as 'youthful,' 'mature' and 'old' is too graphic and compares it with human life. A river valley cannot be compared with human life which has no 'rejuvenation.' There is death after old age in human life; not so for the river.

The leading critics were Chamberlain, Salisbury and Passarge. It must be noted that the critics did not appreciate the difference between 'stage' and 'age.' A river valley may be 'young,' even though in point of time or age it may be 'old.' The following diagrams show the stages of valley development :—

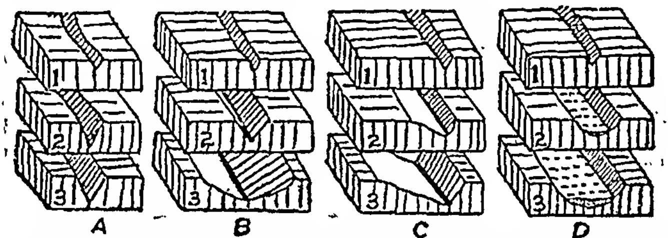



Fig. 125. A, B, C and D are different patterns of valleys as developed by difference of rock structure. 1. shows the youthful stage, 2. the mature stage and 3. the old stage. In A the valleys are V-shaped throughout. In others V-shape is applicable to youth only. In D the U-shaped valleys are characteristic of maturity and old age.

## Action of Waves

We have discussed above the effect of running water as a relief building agent. Here we notice the part played by the ocean water, through waves, in modelling the shore lines. The immense power of the sea waves in breaking the rocks can be realised only by looking at the hilly shore along the Western Ghats in India. The rocks on such coasts are undermined and broken into pieces by wave action. Like powerful mills, the waves pick up the broken pieces again to rain them against the coast and then to grind them into finer and finer rock. The destructive force of waves is most marked against a rocky coast where it is submerging. The erosive power of the waves depends upon the load or sand and pebbles that they throw against the coast.

Another factor which partly helps the wave action against the coastal rocks is the alternate compression and expansion of the air that fills the fissures in the rock. All rocks are fissured to some extent or the other. When a wave strikes against the rock, the air

in the fissure is compressed. When the wave has receded, this air expands again. This alternate compression and expansion of the air in fissures helps to break the rock.

The attack of the waves is most effective on those parts that are exposed to waves coming from the sea. Such parts are generally the promontories or projections of the coasts into the sea. The wave erosion is the least effective in narrow bays or enclosed bays. The effect of the wave action on the projections of the coast is gradually to remove them and thus to straighten the coast.

Wave erosion generally produces steep sea cliffs. These cliffs are eroded quickly if the coast is composed of unconsolidated rock. In harder rocks, however, the erosion is slow and produces caves and rock pinnacles.

The waves and ocean currents deposit some of the material they cut into the protected bays. The deposited material forms beaches of sand or pebbles. The finer material is generally carried back into the deeper parts of the sea. Some of the material also goes to build ridges in shallow waters. After some time these ridges of gravel and sand rise slightly above the water and are known as *spits* or *hook*. On an emerging coast, the waves build *off shore bars* by washing forward loose material from the sea.

## Wind

Wind can change the face of the earth in dry regions just as water does it in humid regions. It is active in desert regions as a relief building agent, because here the weathered rock lies exposed unprotected by water or vegetation. In the deserts the rock weathers largely through the action of frost, for during the day the temperatures are extremely high while during the night they are extremely low. This causes the alternate expansion and contraction of the rock. The dry atmosphere of the deserts intensifies the effect of contraction and expansion. The strain produced by this ultimately breaks the rock. The wind whirls up the fine weathered debris, carries it along as sandstorms and then drives it forcefully against the rocks which it erodes in this way.

The heavier material is moved along the ground and strikes only the lower portion of the rocks. Where the rock is struck by the heavier material, abrasion is the greatest. It, however, rapidly decreases upwards where the rock is met by the finer load of the wind. When the wind direction is variable, the base of the rock is abraded all round and acquires a fantastic shape. The shape of the Sphinx in Egypt is typical of such abrasion.

The erosion by winds is essentially *mechanical* and seldom chemical. This mechanical erosion of the winds falls into three

classes; deflation, abrasion, and attrition. Deflation implies lifting of loose material into the air, while abrasion implies the cutting of rock with which the air currents loaded with the sand particles come into contact. A wind abraded rock is like a polished rock over which a huge sand-paper has been rubbed.

Attrition implies the 'destruction of the tool' of wind erosion, *i. e.*, the sand. The wind now rounds the particles of sand which had at one time cut the rocks. The wind has much greater velocity than water. It also covers much greater distances and areas than a river does. Naturally, it lifts and drops, and whirls and spreads its load of sand. In this process the sand particles become rounded.

Deflation is responsible for many a depression in the desert. Qattara depression in Egypt is such a depression and is 420 feet below sea level. When these depressions have been lowered enough to reach the underground water, they become oases. They are no longer subject to wind erosion, for winds cannot lift moist sands.

The wind picks up loose material from the surface owing to eddies and cross currents produced in the air. Whenever the air currents are direcred downwards to the surface, they disturb the loose material there and lift and deflect into the air the finer particles. This loose material in the air is its load which is the wind's tool for abrasion of other rocks.

Fig. 126. Dreikanter.

The wind cannot carry all the detritus eternally. It must deposit it sooner or later. The deposition of the material held by the wind takes place as soon as its speed falls and there is some obstacle. The chief obstacle is provided by grass. The wind deposited material takes two forms, sand dunes and loess deposits.

The erosive effect of the wind is striking in the carving and shaping of pebbles (known as *glyptoliths* or carve stones). Such stones are generally pitted in the direction from which the wind comes. Sometimes as many as three edges are produced on the pebble by wind action. Such a pebble is called a dreikanter and is shown in the above figure.

## Sand Dunes

The main requisites for the formation of dunes are :—

(1) a source of sand,
(2) a recurrent wind, strong enough to move the sand ;
(3) a place for the sand to accumulate.

In a region having a rainfall adequate for the growth of vegetation, the source of sand must be a locality in which some agent provides a continually renewed bare space from which the wind may pick up sand. This may be a stream bed, a cliff face or a slop below the edge of an escarpment, where erosion is so severe that vegetation cannot grow. The sand picked up prevents the growth of vegetation in the area to which the wind blows and thus extends the source of the sand. The extension of the area free from vegetation or having a vegetation restricted in type and quantity is a prime factor in the growth and the form of dunes.

The strength and constancy of the wind, the quantity of sand, and the climatic factors affecting the type, rate of growth, and degree of continuity of the vegetation cover are the factors that control the size and shape of dunes and the magnitude of dune areas.

Topography, however, is a limiting factor, facilitating or prohibiting the movement of sand.

Where wind and topography are relatively uniform, the two important factors that control the formation of dunes are :—

(*i*) the temperature and humidity and the aggressiveness of the plant cover, and
(*ii*) the quantity of sand that can be put in motion.

Sand dunes may be classified into three simple forms :—

(1) Transverse, (2 Parabolic, and (3) Longitudinal.

These three primary forms occur side by side under the same conditions of climate and wind. Their development depends on the ability of the vegetation cover to resist the movement of sand, which in turn depends on the amount of sand available to the wind for the destruction of vegetation.

(1) *Transverse dunes* occur where the supply of sand is large enough to destroy all, or nearly all the vegetation. They are, therefore, nearly always free from vegetation. In form, they are crescent-shaped dunes whose tails or tips point to leeward. They look like large waves of sand which have steep leeward slopes and gentle windward slopes. Often the waves of sand are separated by narrow areas supporting a meagre growth of shrubs. Transverse dunes can occur in either desert or humid regions; for their formation is dependent on large quantities of moving sand and a lack of vegetation. If the sand moved by the wind is sufficient to destroy all

vegetation over a large area transverse dunes can form even in humid regions.

(2) *Parabolic dunes* are long, scoop-shaped hollows or parabolas of sand, with points tapering to windward direction. The windward slope is much gentler than a leeward slope. Such dunes are formed by the removal of sand from the windward hollows and its deposition on the leeward slopes. They are always associated with a vegetation cover. They support a thin growth of shrubs and bunch grasses suited to their habitat. Encroachment of more aggressive sand binding plants preserves the shape of the dunes and they become fixed. They can form where very great quantities of sand are moved by the wind, provided 'loose sand' plants are aggressive enough to survive the attack.

(3) *Longitudinal dunes* are long, narrow ridges of sand which extend in a direction parallel to that of the prevailing wind. The troughs between the ridges, as well as the flanks of the ridges, may be covered with vegetation; only the long ridge tops are bare. These dunes may be stabilized and preserved by the complete encroachment of vegetation. Given a wind that blows predominantly in one direction, the other prime requisites for the formation of longitudinal dunes are :—(i) a relatively smaller supply of moving sand than is required by the other dune forms, and (ii) a vegetation cover weak enough to permit this supply to be moved by the wind. In regions having an aggressive vegetation cover such large quantities of sand would be required to affect the vegetation that longitudinal dunes would not form. Longitudinal dunes are thus apparently confined to drier regions than the parabolic dunes.

In certain areas migration of the sand dunes is very common. Migration occurs in those cases only where the sand is not bound by vegetation or moisture and where the wind is strong. This is true of drier regions only. The migrations of sand dunes has caused havoc in the past when whole towns have been buried under moving sand. In modern times, the sand dunes in the province of Landes in France have shown the greatest tendency to migration. This migration laid waste large areas of fertile land in France. Migration has now been partly checked by planting grasses and trees on sand dunes.

## Deserts

Wind erosion is marked chiefly in hot deserts where the rocks have no protection of any kind. Due to wind erosion, the hot deserts are divided into three types on the basis of their relief features. These are :—

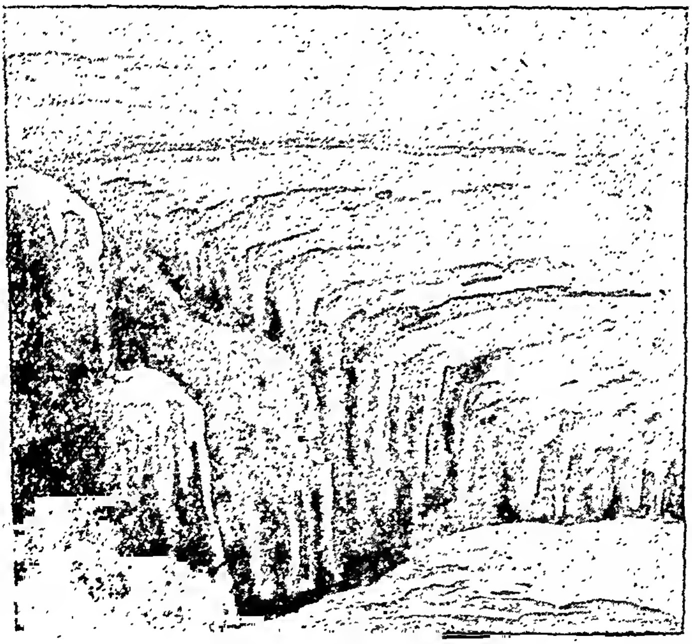
1. The Hamada (a rocky desert, with hills and depressions. The depressions are often filled with shallow salt lakes called *playa*.)

2. The Reg (with stony surfaces that are generally covered by gravels.)

3. The Erg (deserts where the surface is covered by sand.)

## Loess

The wind deposits only the coarser material from its load. The finest material is held and carried long distances away from the source of the sand. This finest material is deposited as *loess**. Three things are characteristic of loess deposits; absence of stratification, the extreme fineness of the particles and massive formation. From these characteristics it is concluded that loess must have



[Photo Smith

Fig. 127. Loess.

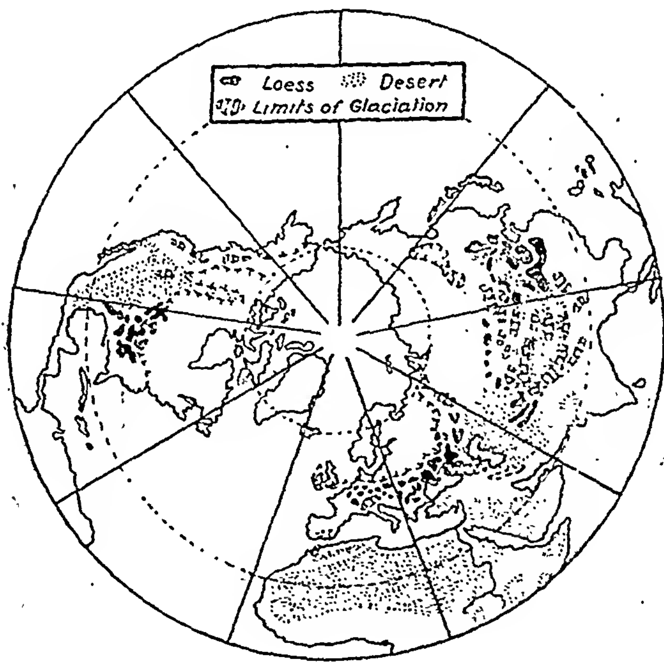
rained down from the air over long periods in the past. The fine dust in the air can only be deposited, without being removed by the wind again, in areas where there is low rainfall and the ground is sufficiently overgrown with thick spreading grass to bind and imprison the deposited particles.

*The word 'loess' was first used in Alsace (France), to denote the deposits of fine dust.

The most striking fact about loess is that it stands in vertical walls when cut through, even though the material is so soft that it will crumble to dust if pressed between fingers. On account of this peculiarity, very narrow vertical tubes penetrate to great depths in this soil without being filled up. These tubes must have been made by the roots of the vegetation that grew on top of the loess. Since loess is very porous rain sinks quickly into it leaving the surface dry.

The distribution of the loess areas of the world is intimately connected with the deserts and the areas covered by the past continental glaciers where the supplies of fine sand are abundant. The thickest deposits of loess are those in the Kansu and Shansi provinces of China where the thickness reaches about 200 feet. In Europe and America, however, the thickness varies about 20 feet.

The following diagram shows the distribution of loess as well as its connection with deserts and glaciation.




[After De Martonne

Fig. 128. Loess Distribution.

## Vulcanism

Vulcanism is defined as a process whereby the molten rock is ejected from the interior of the earth. This matter is ejected through openings in the earth's crust which are called 'Volcanoes'. Amongst all the great phenomena displayed by nature, nothing is more impressive than volcanoes. Yet our knowledge about vulcanism is scanty and the subject is not yet out of the field of controversy.

If we accept the hypothesis that the earth has formed from cooling of gaseous matter, it must follow that vulcanism was much more intense in the earliest times, because, with the passage of time, the outflow of magma was made more difficult by the thickening of the earth's crust. On this basis the following may be regarded as the different stages in vulcanism :

(1) *Superficial Eruption.* When the magma could easily break through larger surfaces and quietly melt through the thin earth's crust.

(2) *Fissure Eruption*—When it had to confine itself to some weak zones.

(3) *Central Eruption*—When it came to the surface through more explosive work.

The escape of the gases imprisoned and enclosed in the plastic magma seems to be the main cause of vulcanism. We see gas emerging everywhere from active volcanoes. The last convulsions of dying volcanoes are always the production of enormous amounts of gas. Therefore, it cannot be doubted that there is gas in the magma. Gas is no passive substance, and it makes its presence felt as soon as it finds an opportunity. The maxim, therefore, is 'no gas, no volcano.'

A volcano's form and activity are now attributed to the composition and the gas content of the feeding magma. Magma is distinguished into 'granite' magma (coming from deeper layers) and 'basalt' magma. Granite magma is called 'acid' on account of its silica content and is rather rich in gas. The basalt magma is called 'basic' magma, because of its higher position in the earth's interior.

Great differences of flowing capacity seem connected with the silica and gas content. Basic magmas containing little gas rise up quietly in the feeding channels and the highly fluid lava flows out just as quietly on the surface without violent eruptions. The rate of lava flow on the surface, in this case, is so great that a rider on horse-back can only keep pace with it with the greatest difficulty. The extruded products solidify directly from the magma, and from

long connected streams of lava. The cone, built up round the crater has only shallow sides. This is seen in the 'Shield Volcanoes' which embody the ideal superficial form of this *effusive vulcanism.*

Highly gaseous acid magmas, on the other hand break out under high pressure with very violent eruptions or explosions. The volcanic products thus ejected are loose fragments, for the viscous lava is shattered during the eruption and flung away as blocks, bombs, scoriae, smaller grains and the fine dust. The volcanic tuffs—which are simply great accumulations of volcanic ash—with a few larger blocks or bombs scattered in it, often cover considerable areas, giving the landscape a very characteristic appearance when erosion has completed its work later on. The discharge of gas comes out with such force that the volcanic products are strewn in all directions, no longer falling near the vent to build up a cone of any size.

Based on the two types of magma, we can divide vulcanism into : (i) effusive vulcanism and (ii) explosive vulcanism.

## Volcanic cone

The matter that is thrown out by the volcanoes consists of (i) gases, (ii) cinders or volcanic ash, and (iii) lava. The gases escape into the air, but the cinders and the lava are deposited around the volcanoes forming the volcanic cone. These cones form hills with a hollow at the top. This hollow is called the crater. The crater is generally round, except where a particular wind direction is dominant, as in the case of the *Teneriffe,* in the Canary Islands near Africa, which is subjected to trade winds. In some cases where the volcano is now extinct, the crater may be filled by a lake.

The cinders and lavas produce special types of cones. The cinder cones are generally perfect cones with a curved profile, as they spread out towards the base. The development of the cone is due to the falling of the volcanic ash around the volcano. The successive eruptions of the volcano deposit layer after layer of the ash on the sides of the cone. Towards the top the cone is rounded in a concave shape.

The lava cones are built generally by acid magma which is viscous or pasty and cools down quickly. Such lava cones are often dome-shaped with steep sides. The acid magma cools down and blocks the mouth of crater. The successive flows of lava have to exert pressure on the obstacle blocking the passage as well as on the walls of the cone. Sometimes a fissure created in the walls and the lava flows out through this new opening on the side. This fissure develops later into a *subsidiary cone.* When the pressure of the lava in the passage is very great the obstacle is blown out together with a portion of the walls of the crater. A wide mouth is thus formed

on top of the cone which is called a *caldera.* Very often, as in the case of the Vesuvius, a new or *adventive cone* is formed within the caldera.

In the case of the basic lava the dome that is built round the volcano is very flat with gently sloping sides. The lava flows cover a large area. For example, the whole of the island on which the famous Hawaiian volcano, Mauna Loa, stands has been built by the lava flows from the volcano. The volcano also shows the gentle slope of volcanic dome. For, even though the volcanic dome attains the height of about 14,000 feet, the angle of the slopes rises gradually from 4° to 6°.

The following diagrams show the various kinds of cones developed by volcanoes :—

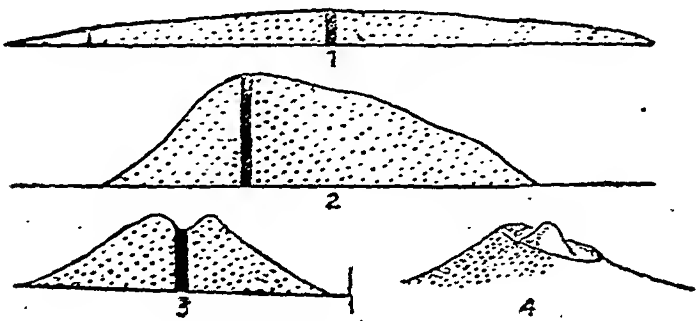



Fig. 129. Volcanic Cones.
(1. Basic Lava Dome, 2. Acid Lava Dome, 3. Cinder cone, 4. Caldera and Adventive cone).

Long after the eruptions have ceased a large amount of steam and gases still escape from the crater of a volcano. If these gases contain and precipitate enough sulphur, the volcano is called a *solfatora*, after the name of the extinct solfatora cone in the Phlegrian fields near Naples, where sulphur has been obtained from the deposits of these gases from ancient times. 'Solfatora' indicates the dying state of a volcano.

To this state of vulcanism also belong the warm springs and geysers, and to some extent the 'mud' volcanoes also. There are three volcanic regions where hot springs and geysers occur on an imposing scale ; Iceland, U.S.A. (Yellowstone Park), and the North Island of New Zealand. The mud volcanoes are due to the coloured warm mud springs in which the water evaporates more quickly than it is supplied from below, so that the detritus dragged along is deposited on the surface as a mud cone with little craters.

In India, mud volcanoes occur on both sides of the Arakan Yomas. On the Burma side, the group comprises the mud volcanoes in Minbu, Prome and Henzada districts. On the Indian side, it comprises of the mud volcanoes on the Arakan coast, especially on the islands of Ramri and Cheduba near Cape Negrais.

There are two chief characteristics of volcanic relief. In the first place, it has no connection whatsoever with the geological structure of the surface where it is formed. The volcanic cone may rise as a hill in the midst of an alluvial plain where no hill can form. In the second place, this relief is brought into existence suddenly. No other agent can build relief so soon as vulcanism. A hill may be created by a volcano almost overnight. In fact, Monte Nuovo in Italy *was* built in one night. Similarly, about two-thirds of the island, in the Sunda Strait between Java and Sumatra, on which Krakatoa stands was blown way in a few minutes.*

The original relief built by the volcano is later modified by erosion.

The following account of the Crater of Nyamlagira in Belgian Congo† gives a graphic description of what a crater is like :—

"The crater is about 2 miles in diameter and 300 feet deep, and on the northern side there is an opening through which we passed. There are actually two craters, the active one, which, about 1½ miles across, lies within the older crater, and was a few years ago several hundred feet deeper, but the lava has now risen to within 100 feet of the surface. The floor of the old crater is split up with numerous cracks ; steam is shooting out in many places, and near where we camped there is a group of sulphur jets which send a white barrage of asphyxiating fumes across the view. The ground here is very treacherous and we walked continually with a stick, feeling for hidden cracks before advancing. Looking into the active crater one sees a seething turmoil of steam, flame and smoke. There must have been at least 600 acres of lava, twisted and distorted and split up with numerous cracks. The molten lava oozes up through these cracks, flowing in a thick red stream over the surface. Protruding above the lava bed, on the southern side, stood a group of five small cones or chimneys, which shot up huge columns of blue and white smoke and occasional bursts of flame. They were about 20 feet high and 100 feet across, and from our higher view-point we could see the red molten lava boiling inside. Spasmodic burst of flame shot up from below with a loud roar, throwing the red lava high into the air. Around the black sides of these cones lay acres

*1. Mirford-Barberton in Geog., Jour. Vol. 89, 1937.

†The Volcano became active in May, 1883. On the 27th of August, 1883, there were four very big explosions. These explosions were heard as far away as Australia ; when the dust clouds cleared, part of the island was found missing.

of yellow sulphur which had condensed from the fumes. We were unable to get close to these chimneys, as they were cut off by the perpendicular wall of the crater on one side and acres of hot lava on the other.

The fumes and smoke here were very dense, and below hither and thither with the wind, often hiding the view entirely Away in the centre of the lava rose great island of rock rather like Gibraltar in appearance. It stood out 100 feet above the surrounding level, and was doubtless a cone or core from some previous eruption.

Climbing down into the active crater we walked for a few hundred yards on the lava where it was not too hot. We had to choose our way carefully, jumping over the cracks and making sure that the heat was not too much for our feet. Occasionally we saw the red glow of molten lava down in the cracks, but here the heat was so intense that even a quick glance nearly sign:d our eyebrows. The green sticks with which we were walking caught fire immediately when thrust into the cracks, and we lit cigarettes from a small fragment of stone we chipped from the red-hot sides. Occasionally we found the lava too hot for our feet and had to retreat.

By night the crater was wonderful sight, even more grand than it was by day. Columns of flame burst up from the chimneys, lighting the pall of smoke which hung overhead. From a narrow crack in a huge black rock a white-flame 20 yards long shot out at regular intervals and with the report of a cannon. All night long we could hear the roar of this particular jet above the general noise of the crater. On the second night it was silent, and had no doubt blown itself to pieces."

## Geographical Distribution

The geographical distribution of volcanoes shows that it is related to the 'zones of weakness' in the earth's crust. Such zones lie where the crust has been folded. The distribution follows a line running from Alaska to Patagonia in New Zealand through Japan, Philippines and Borneo. An off-shoot of this second line runs to the north-west covering Java and Borneo, etc. A third line follows the great African rift valley, while a fourth line follows the fold mountains of Eurasia shows the distribution of volcanoes. Fig. 130, on page 257 shows the distribution volcanoes.

## Earthquakes

The earthquake is, generally speaking, an intense disturbance on the earth's surface, caused by certain movements in the interior. The place into the interior of the earth where these movements start is called the *hypocentre*. The hypocentres sometimes lie several hundred miles deep into the heart of the earth. The place on the

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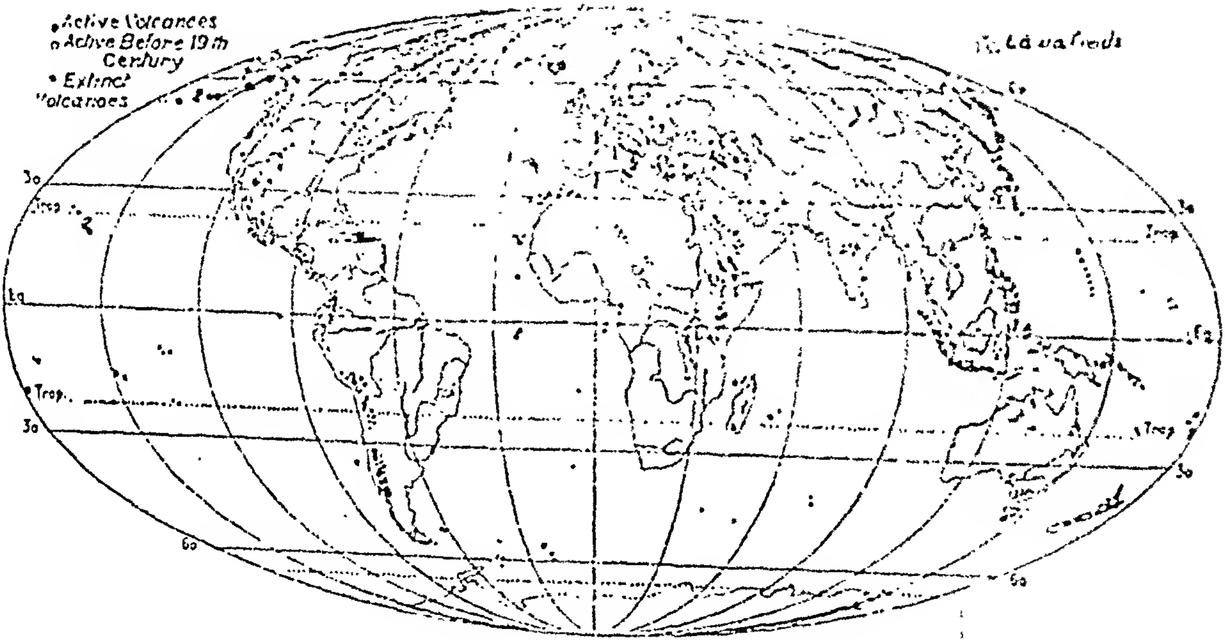


[After De Martonne.

Fig. 130. Distribution of Volcanoes.

earth's surface to which the vibrations are communicated from the hypocentre by the elastic rocks and from which the disturbances spread on the surface is called the *epicentre*. The tremor of the earth is the most intense at the epicentre and, therefore, the consequences are the most catastrophic here.

It has been known for some time that three distinct types of waves are produced by an earthquake shock (i) the compressional or *pushwaves*, (ii) the distortional or *shake waves* and (iii) *surface waves*. The first two types penetrate to a considerable depth below the surface of the earth, while the third tends to die away somewhat rapidly in the depth. The push and shake waves sometimes occur in two or three distinct pairs. From this fact it has been inferred that the earth's interior consists of different layers with distinct elastic properties. For the velocities of the earthquake waves depend upon the elastic properties and the density of the material through which they travel.

The complexity of the motion accompanying the quake shock can be judged from the descriptions of witnesses of the Quetta Earthquake of 1935. The witnesses felt horizontal shaking both from north to south and from east to west, as well as vertical movement. Some of the stone monuments in the Quetta Cemetery were found to have rotated on their bases, one of them to extent of 43 degrees anticlockwise. According to one witness the main shock came from the south. It was preceded by a rumbling sound which resembled the sound heard in an underground railway tunnel as the train approaches the station. The ground heaved as a boat heaves in a rough sea. Some witnesses also described that the trees on either side of the roads swayed violently to and fro until branches touched the ground.

There are two broad classes of earthquakes; volcanic earthquakes and tectonic earthquakes.

Volcanic earthquakes are those that are connected with several volcanic eruptions. They are comparatively unimportant from the point of view of the area affected and the damage done. The tectonic earthquakes are caused by the accumulated stresses in the earth's crust which ultimately lead to fractures of the crust and sudden shocks.

The majority of earthquakes are the consequences of fracture formations in the earth's crust, or of displacements along already existing fractures. These fractures need not always be visible on the surface. But the presence of epicentres betrays their existence. For example, the earthquakes in California in 1868, 1872 and 1906 were all connected with the San Andreas Fault. The Quetta Earth-

quake of 1935 was itself connected with the Chiltankalat line of fissuring as will appear from the accompanying map.

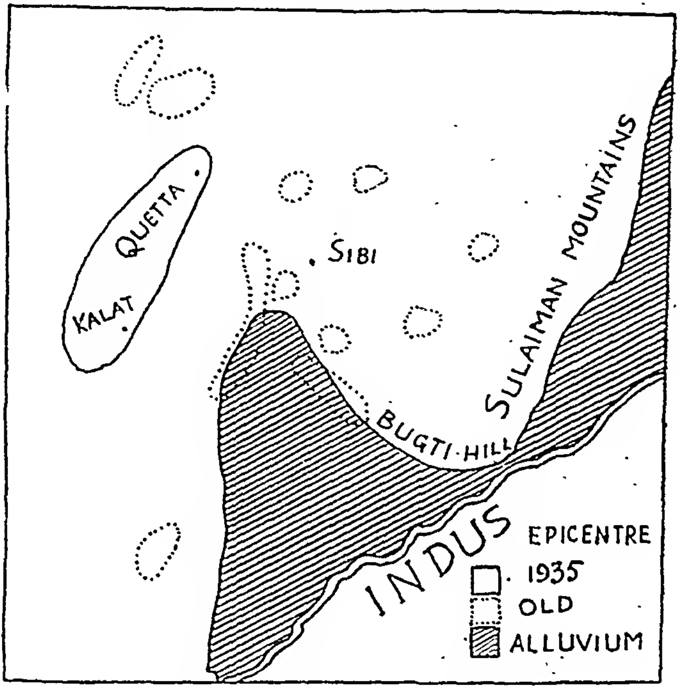


*Fig.* 131. Baluchistan Earthquake zone

It is now generally accepted that the folds in the Tertiary mountains system, of which the mountains of Baluchistan are merely a southward extension, have been formed by the movement of the old stable mass of Central Asia towards the stable mass of peninsular India, resulting in the compression of the soft rocks in between to form the mountains. The epicentres of the recorded earthquakes are grouped round a sharp re-entrant which exists in the mountains of Baluchistan. The mouth of the Bolan pass and the town of Sibi, only 450 feet above the level of the sea, are at the head of this re-entrant. The hills on the western flank of this re-entrant rise to about 10,000 feet in the Kalat territory. Those on the eastern flank also are very precipitous.

The re-entrant may have been caused by a wedge of continental India jutting north-westward under the alluvium of the Indus Valley. which has held up the movement of the folds to the south-east. The

result of such a condition must produce a special strain which is likely to cause earthquakes.

In folded regions the epicentres lie on *longitudinal fractures* along which the folds run in the direction of original folding, or on *oblique fractures* which form when folding cannot continue further without the earth's crust breaking. The earthquakes are frequent and intense in places where different systems of fractures meet. The towns of Osaka and Kioto are situated on an oblique fracture on the Japanese coast.

The most important results of the earthquakes in relief building are the earth displacement, sudden changes of level, and the fractures and fissures formed in the earth's crust. Since earthquakes are in many cases associated with steep slopes, landslides are a common accompaniment. Some of these have dammed up streams and thus produced new lakes.

### In Japan

Japan is the most quake-affected country of the world. The Japanese earthquake of September 1, 1923, will be remembered for a long time, even though it was not among the greatest of those that have visited Japan in the past. Compared with some of the other earthquakes the loss of life in this Japanese earthquake was also not so high. For the total number of persons known to have perished was 99,000 as compared to 100,000 in the Messina earthquake of 1908, and 180,000 in the Chinese earthquake of 1920. The Japanese earthquake is to be remembered more for the destruction caused by the fire that broke out after the earthquake than for the injuries directly due to the shock itself. The loss of property was, therefore, more serious than the loss of life.

In the neighbourhood of Tokyo there are several well-defined earthquake zones. From 1914 to 1921 there were about 200 shocks in Japan, almost all of them originated in the four areas given below :—

1. The submarine band lying off the east coast of the Main island,
2. The eastern half of the Boso Peninsula and the adjoining sea bed,
3. The area north and north-east of Tokyo, and
4. The northern half of the Sagami Bay and the country beyond.

The September earthquake originated at a point to the north of Oshima and about two-fifths the distance from that island to the north coast of Sagami Bay.

It is estimated that the motion at Tokyo due to the great shock lasted for about two hours and twenty minutes. Almost exactly 24

hours after the first shock, at 11·47 on September 2, another earthquake occurred, which was nearly equal in strength to the former but quite different in origin. The epicentre of this second shock was to the south-east of Katsuura in the Boso Peninsula.

As a result of these earthquakes there were changes in the level of the sea coast. In the Miura Peninsula the ground was raised by amounts varying from 2 to 5 feet at its southern point. Similar elevations occurred all along the coast of Sagami Bay and its western coast as far as Ito. Along the whole coast of Boso Peninsula the land was raised. But subsequently the elevations subsided.

The following sketch shows the earthquake Zones of Japan :—

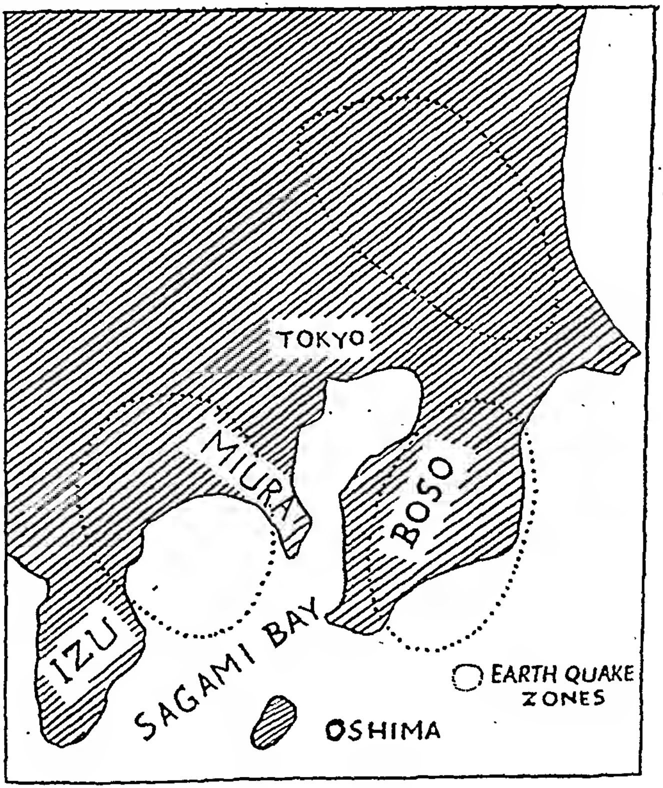


Fig. 132. Japanese Earthquake, 1923.

## Geographical distribution

A very high percentage of all earthquakes and all but a few of the major ones are found within two great belts; the Mediterranean-Pacific and Mid-Atlantic. The principal one may be called the Mediterranean-Pacific. This is a simple belt of varying width running from west of Spain and Portugal to India and around most of the Pacific ocean. Towards the south-east it is more complex. One branch goes from Burma along the Dutch East Indies to New Guinea. Another extends from Japan to New Guinea by way of the Philippines. Still a third extends from Japan to New Guinea by way of the Bonin and Lariana islands. A portion of the belt surrounds the Caribbean Sea. There are several side branches.

The Mid-Atlantic belt differs from the great belt in important particulars.

The number of earthquakes, and specially of major shocks are small in comparison. While the oceanic parts of the great belt follow continental shores or large island groups, the Mid-Atlantic belt is in mid-ocean, and includes only a few islands. By far the most active part of this belt is along the equator. The activity in the South Atlantic is low, with only a few epicentres near Tristan da Cunha, but nearer the Antarctic continent it becomes considerable.

Since earthquakes are often associated with mountain building, it is not surprising to find within the great earthquake belt the mountain systems of Southern Europe, most of the great chains of Southern Asia, including the Himalayas, a considerable portion of the mountains of North America, and practically all of the Andes.

Its submerged island chains include the East Indies. Practically all the great ocean troughs are within this belt.

Finally the greatest known rifts are found in it: San Andreas, which extends from an unknown point off the coast of Oregon, through California into Mexico, and the Syro-African system.

The conditions of the Mid-Atlantic belt are quite different. There are no mountains or submerged island chains in it. The only possibility of troughs is in the few deep soundings in the equatorial region. The outstanding feature of this belt is that it follows the Mid-Atlantic ridge.

In India, the earthquake region is connected with the Himalayas. The region follows the junction of the Tertiary rocks with the older rocks, where the wedge-like masses of the old rocks have opposed the advance of the Himalayan folds towards the Peninsular

area. Here runs the Great Himalayan Fault. The most important areas of earthquakes, therefore, are:—

1. Sadiya region on the Chinese border,
2. Kashmir region,
3. Quetta region, and
4. Northern end of the Sulaimans in Waziristan.

Besides this main earthquake region of India, shocks also arise in the Indo-Gangetic Plains and the Assam Plateau. The earthquake activity in these two areas is connected with faults that underlie there. The Bihar earthquake of 1934 has been attributed to the fractures in the floor beneath Motihari and Monghyr.

Quite as interesting as the earthquake belts are the detached earthquakes, many of which are of major intensity. The following diagram shows the earthquake zones:—

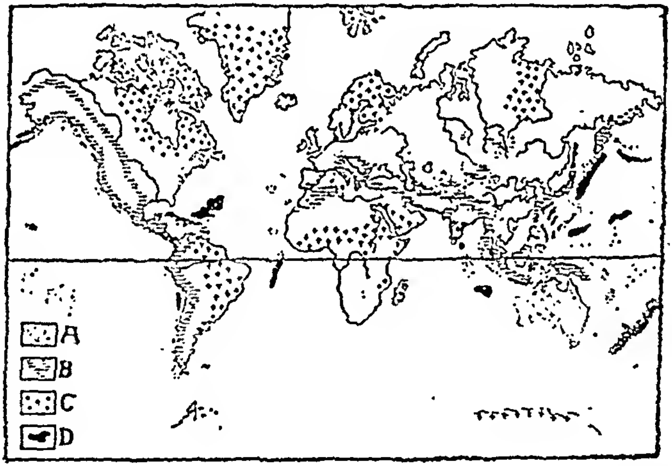


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Fig. 133. Earthquake Zones.

(A. Main Belt, B. Zones of weakness due to Tertiary Mts. C. Faults of old geological periods and D. Greatest depths.

## Coral

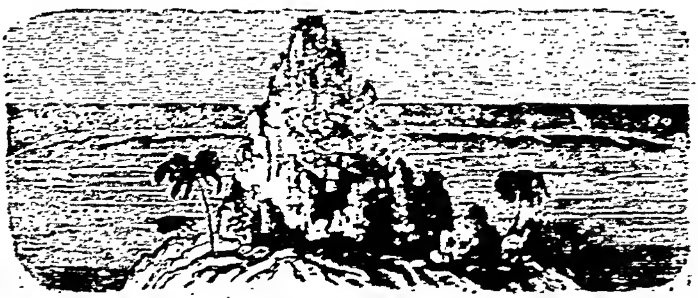
Insect life in the oceans is sometimes responsible for certain relief features which are not built of 'rock' in the strict sense. The relief consists of living or dead bodies of insects. But the foundation of this relief rests on true relief as produced by 'rock'. As

will appear here, the provision of the foundation is intimately connected with tectonic forces. In some parts of the world the continents and islands are fringed by reefs which have been built by certain types of insects, the most common of which being the coral-producing madrepores. As these insects can develop best in warm seas, it is between 30°N. and 30°S. of the equator that the most extensive coral reefs are found. They are specially marked in the Pacific. The most suitable temperatures of water in which the reef-forming madrepore can live vary between 68° and 85°F. The reefs are built by the skeletons of the insects which abound in carbonate of lime.

Observation has shown that the formation of coral reefs requires three things: clear water free from sediment, depth of water about 30 fathoms, and warm temperatures. Corals are not found beyond a depth of 300 feet. The formation of the coral reefs starts in the sea from the bottom *upwards* and *outwards*. After some time the top of the reef just reaches the top of the water above at low tide.

The growth of the corals outwards progresses more rapidly, because of the greater food being available for the insects there, than inward. This part of the coral mass reaches the water first. The coral reef, therefore, rises rather steeply from a depth of about 30 fathoms and slightly slopes towards the land. This slope separating the higher part of the outer coral mass from the land is covered by water as a lagoon.

Coral reefs are divided into three classes, according to their form. These classes are, fringing reef, barrier reef and atoll. The *fringing reef* is one that is situated near the margin of some landmass. It is covered by water and does not rise above it. The lagoon that separates it from the land is very narrow and shallow. The *barrier reef*,



[From Obst.

Fig. 134. Atoll.

on the other hand, is separated from land by a deeper and much wider lagoon. The barrier reef almost always rises above the water. The Great Barrier Reef lying off the Australian coast is in some places about 150 miles away and runs along the coast for about a thousand miles. When a coral reef attains the shape of a ring or a horse-shoe it is called an *atoll*. In the atoll the lagoon lies in the centre.

In the picture in fig. 134 the dome in the centre is an island. The outer white ring is the Atoll. The water between the dome and the ring is the lagoon.

The opinion on the mode of the coral reef formation is still divided. There are two theories in the field. *Darwin's theory* says that all coral reefs originate as fringing reefs and the lagoon, which is an essential accompaniment of a coral reef, develops owing to subsidence of land. The process of reef formation by the growth of insects on the outer margins continues with this subsidence, so that while the lagoon deepens and broadens the reef maintains its position above or on the water. In this way atolls form by the subsidence of islands round which fringing reefs had formed.

The points in favour of Darwin's hypothesis of coral reefs are :—

1. The actual samples of the reef obtained from the depths by dredging show that the reef was "drowned" or killed while it was still growing. The area must, therefore, have suffered submergence.

2. The great thickness of the coral reef indicates that its beginnings were made on a subsiding base. For the coral cannot live in greater depths.

3. The small islands forming the atolls do not show subdued slopes produced by normal denudation. It can be concluded, therefore, that they are the remnant peaks of a much larger mountain that has submerged.

4. There is an unconformity in the contact between the land and the reef. In a normally denuded land the margins are sloping downward. In the case of the reef, there is an upward slope.

5. There are many bays around the lands surrounded by reefs. These bays are the valleys of rivers that have now been submerged.

6. In the case of islands about which there is a definite proof that they have emerged there is no reef.

Another explanation of the existence of the reef was offered by Daly in his *glacial control hypothesis.* Daly stated that the level of the tropical seas was lowered by about 200 feet to 300 feet during the period of glaciation as large quantities of water were imprisoned in the ice sheets. This conclusion was based on his observation that the depth of the larger lagoon floors is uniform, and that the sub-lagoon floors exist at a depth of 200-300 feet. He believed that these platforms were created by wave-erosion on stable islands during the glacial period.

This hypothesis was criticised by Davis on the ground that the observed facts did not bear out Daly's observations. Even within one atoll Davis found the depths varying from 20 feet to 300 feet.

*Sir John Murray's theory* says that the formations of the coral reefs started on foundations of non-coral origin. These foundations were generally provided by volcanic cones under the sea or by the talus washed down from existing reefs and lands. The carbonate of lime on the inner side of the reef, where the growth stopped after some time, dissolved and provided the hollow which is filled by the lagoons.

Apart from the Great Barrier Reef of the North East Australia, the New Caledonian reef is the largest specimen of its kind in existence. Excluding the Loyalty Islands, coral reefs enclose the whole of the New Caledonian Archipelago from the Huon Islands in the extreme north through the islands of Pott and Art, the small islets of Yande, Neba, etc., and the mainland of New Caledonia proper to the Isle of Pines in the extreme south. Whole of this reef is essentially a single formation.

The coral attains its most perfect development as a barrier reef on the east coast, where no extensive fringing reef is developed. The barrier reef lies at a distance of 1 to 8 miles from the land. Outside this reef soundings reveal great depth but inside there is a comparatively shallow channel. This channel is the deepest in the middle, and becomes shallower both towards land and towards the reef. Generally speaking, the reef is single, and forms a band of coral rock awash with the sea, interrupted here and there by numerous passes. In these passes the water is approximately of the same depth as that in the middle of the channel. In most cases the passes in the reef lie opposite the mouths of rivers. This is a strong piece of evidence for the view that the barrier reef began as a fringing reef, and that it was gradually separated from the land by subsidence of the whole region. At a distance of several miles it is inconceivable that fresh water discharged by the rivers into the channel

could suffice to prevent the growth of the coral in the passes of the reef. On the other hand, if such a pass existed for any reason it would certainly be kept open by the scouring action of the tides. The structure of the reefs is adequately explained by the theory that they are the direct descendants of fringing reef, which were naturally interrupted by the river mouths.

Apart from the arrangement of reefs and the geological structure there are certain features of the coastline which make it probable that a subsidence has occurred. There are narrow inlets. There is a fringe of islands.

The coral formation of which the Loyalty Islands, the Isle of Pines, and the Yate strip are composed is frequently very much altered by the action of water, being tunnelled out and precipitated as stalactites and in various crystalline forms.

CHAPTER XIV

# HYDROSPHERE

OCEANS—CONTINENTAL SHELF—OCEAN CURRENTS—GULF DRIFT—TIDES—PROGRESSIVE WAVE THEORY—STATIONARY WAVE THEORY—COAST—LINE—FIORD COAST—RIA COAST—UNDERGROUND WATER—ORIGIN OF SPRINGS—LAKES.

Hydrosphere consists of all water on the earth whether collected in large bodies on the surface as in oceans or lakes, or contained in the rocks of the earth's crust. The significance of hydrosphere is great, as roughly about three-fourths of the earth's surface is covered by the oceans alone. Without water there could be no life on the earth. The abundance of overground and underground water on our earth is in complete contrast with the conditions obtaining on our neighbouring planet the Mars and our satellite the Moon which have little or no water. Considering the needs of organic life on the earth, however, the area of the oceans here is none too large. A smaller area of the oceans would not be enough either to keep the life processes going by supplying the needs of water, or to regulate the temperatures on land. The extremes to which the unregulated temperatures on land could go would destroy practically all life on it.

We have already considered under climate the effect of oceans as a store-house of heat and a store-house of rain. For the ocean water modifies the temperatures of air and supplies it with moisture which is distributed on land as rainfall. This rainfall gives rise to lakes and rivers and is the chief source of underground water which makes its appearance through springs or artesian wells.

## Oceans

The origin of the oceans is still a mystery. The vast mass of the ocean water, disturbed by storms and gales, over which man cannot go as he does on land is naturally a barrier to our knowledge of the oceans. The ocean bed is hidden from the eye of man. It is only indirectly through 'soundings' or through radar that we deduce certain things about the ocean bed. From soundings taken from ships in different parts of the oceans, we find that the oceans are like soup plates and not like saucers. That is to say, beginning from the shore, the depth of the water increases gradually for some distance and then there is a sudden increase in it. In other words, there are two parts of the ocean, one covering the *continental shelf* and the other filling the *ocean basin*.

There is evidence to show that the ocean bed is marked by the same kind of irregular relief as characterises the land surface. An important feature of the irregularity of the ocean bed is the presence of the 'submarine canyons' where the depth of the water is several miles. These submarine canyons are very much similar to the canyons occurring on land and may have been formed by the faulting of crust. In some cases the submarine canyons continue the lines of large rivers on land, as if the rivers once flowed right through these canyons into the open sea. The canyons continuing the line of the Hudson river under the sea is an example. The deepest parts of the ocean lie in the Pacific. The deepest sounding so far recorded is 35,400 feet in the Swire Deep near Mindanao in the Philippines.*

Besides the submarine canyons the presence of several sharp ridges, almost like cliffs on land, on the ocean floor has also been established. The most remarkable ridge of this kind is the Atlantic Ridge found to the north-east of Porto Rico. The following diagram shows the ocean depths :—

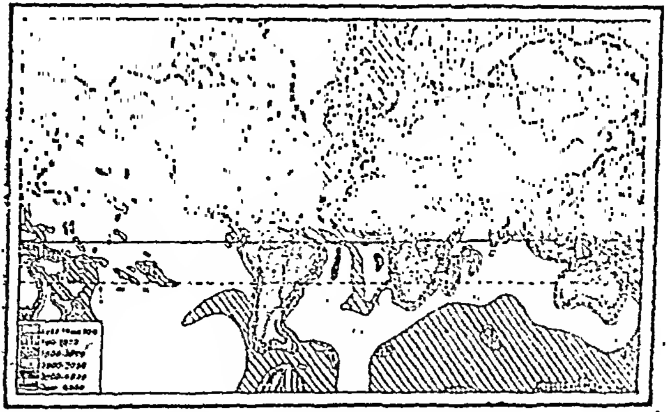


Fig. 135. Ocean Depths (In fathoms).
(The 100 fathom line marks the limit of the continental shelf.)

A geographer's interest in the oceans lies in shorelines and tides which affect the development of ports, and the ocean currents which influence the climate and fisheries of coastal regions.

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* Other deeps are :—

Ramapo Deep, off Japan, 34,626 ft.
Nero Deep, south-east of Guam, 31,614 ft.
Milwaukee Depth, north of Hispaniola, 30,246 ft.
Wharton Deep, south of Java, 22,968 ft.
Bartlett Deep, south of Cuba, 22,788 ft.

## Ocean Currents

Surface movement of the ocean water takes place on account of the following factors :—

(*a*) Winds,

(*b*) differential heating, and

(*c*) different densities of water.

The prevailing winds near the equatorial region move before them the lighter water floating on the ocean surface. This movement takes the form of a slow-moving *drift* whose average speed is about 2 to 3 miles per hour. The great heat received in this region causes the surface water to be greatly heated and to expand. It is this expanded water which floats on the ocean surface.

The ocean drift led by the prevailing winds of the tropical region is made to follow the course determined by the shoreline. The ultimate direction of the drift, therefore, depends on the continental coastline, and the rotation of the Earth as expressed in Ferrel's Law. Where the drift has to pass through a narrow strait its speed is considerably increased and it becomes an *ocean current*. In the higher and middle latitudes the drift is led by the prevailing westerlies.

The effect of the rotation of the earth is also felt on the movement of the currents and drifts. Right or left deflection of the currents, according as they are in the northern or the southern hemisphere, is common.

The source of warm water is in the lower latitudes, owing to the greatest intensity of the sun's rays there. When this warm water is moved in drifts and currents away from its source, there is a counter-balancing flow of cooler water from the higher latitudes. The movement of ocean water, therefore, gives rise to two different types of currents, *warm currents*, and *cool currents*. The warm currents move poleward, while the cool currents move equatorward. Owing to the effect of the earth's rotation, however, the equatorward moving *cool currents wash the eastern shores in high latitudes and western shores in lower latitudes* in the northern hemisphere; while the poleward moving *warm currents wash the eastern shores in the lower latitudes and western shores in the higher latitudes.*

The density of the ocean water is not the same everywhere. In cooler regions and in regions where the salinity of water is great, owing to greater evaporation, the waters are denser or heavier than in areas where the waters are warmer and salinity less, owing to greater mixing of fresh waters derived from rainfall and from rivers draining into the seas. The denser water sinks below and bubbles up in the region where the water is less dense. This bubbling up of cooler water is most marked on the Peruvian coast.

Sometimes the character of lake water is changed entirely by the salt content of water. The following account* of the Dead Sea is of interest to us : "I bathed in the Dead Sea. The ground covered by the water sloped so gradually that I was not only forced to "sneak in,"

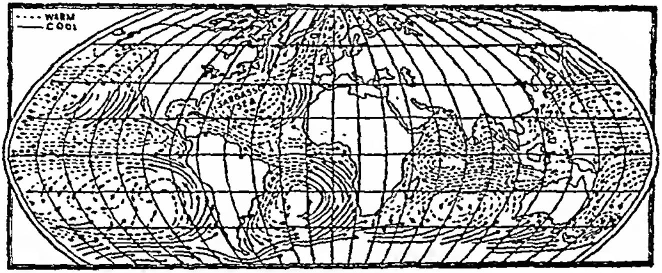



Fig. 136. Ocean Currents.

but to walk through the water nearly a quarter of a mile before I could get out of my depth. When at last I was able to attempt to dive, the salts held in solution made my eyes smart so sharply that the pain .... made me giddy and faint for some moments. I knew beforehand the impossibility of sinking in this buoyant water , but I was surprised to find that I could not swim at my accustomed pace : my legs and feet were lifted so high and dry out of the lake that my stroke was baffled, and I found myself kicking against the thin air, instead of the dense fluid upon which I was swimming. The water is perfectly bright and clear ; its taste detestable. After finishing my attempts at swimming and diving, I took some time in regaining the shore ; and, before I began to dress, I found that the sun had already evaporated the water which clung to me, and that my skin was thickly encrusted with salts."

The most prominent ocean currents are found in the North Atlantic. The main reason for this is that, owing to the bulge of the Brazilian coast, the greater part of the equatorial ocean drift is diverted north of Cape Saint Roque into the North Atlantic. This drift ultimately becomes the famous 'Gulf Stream' of the North Atlantic. Another reason is the enclosed character of the waters of the Arctic Ocean The main opening of the Arctic is into the North Atlantic and not into the Pacific. This causes the large counter-flow of the Arctic waters into the North Atlantic near Greenland.

Fig. 136 on page 271 shows the distribution of ocean currents. The warm currents are :—

1. The Gulf Stream in the Atlantic which branches off towards the north-east into the West Wind Drift and the Atlantic Drift.

*Kinglake's Eothen, Everyman's Library.

2. The Kuro Siwo, east of Japan, far off from coast.

3. The North and South Equatorial currents, with numerous branches.

4. The Brazil current, east of South America.

5. Agulhas and Mozambique currents, east of Africa.

6. East Australian current, east of Australia. New Zealand is completely surrounded by it. Australia is also almost completely surrounded by warm currents.

The cool currents are :—

1. The Labrador current, east of Canada.
2. The Greenland current, east of Greenland.
3. The California current, west of U. S. A.
4. The Oya Siwo or the Sakhalin current, near the eastern coast of Japan.
5. The Peru current, west of South America.
6. The Benguella current, west of Africa.
7. The West Australian current, far off from the western coast of Australia.

## Gulf Stream

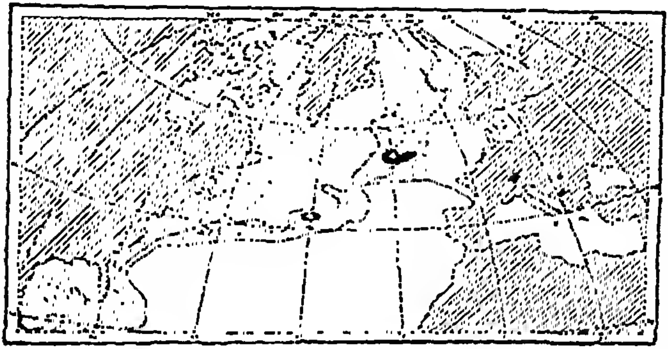
After being deflected to the north by the Brazilian coast greater part of the North Equatorial drift forms into a slow-moving eddy known as the Sargasso Sea. A portion of this drift, however, enters the Caribbean Sea and then passes through the Yucatan Strait into the land-enclosed Gulf of Mexico. Here it is considerably warmed. The water piles higher and higher into the Gulf until it issues through the narrow Florida Strait as the swiftly moving 'Gulf Stream' into the open ocean where it joins the rest of the drift. It has been estimated that about two-fifths of the waters of the North Equatorial drift enter the Caribbean Sea.

The general direction of the flow of the Gulf Stream, north of the 30°N., latitude is northward. But beyond Cape Hatteras it bends slowly to the right, passing 210 miles south of Nantucket until south of Halifax the flow is nearly due east. Where the Gulf Stream leaves the continental shelf at Cape Hatteras, its average width is about 50 miles. Eastward, it widens gradually, becoming 70 miles wide in the longitude of Halifax.

It is between Cape Hatteras and Nova Scotia that the full development of the Gulf Stream is attained. Though its surface speed falls to about 2 knots, its volume increases considerably until it carries three times as much water as it did when it left the Florida Strait. It has been estimated* that the Gulf Stream here carries seven hundred times as much water as the greatest flow of the river Mississippi.

*The Geographical Journal, August, 1941.

The next important change is noticed as the Gulf Stream curves to the east, south of Nova Scotia. It now broadens out, until to the east of the Newfoundland banks it divides into three branches. The main branch goes towards the north-western Europe, the second branch goes towards the Portuguese coast, and the third returns towards the Sargasso Sea. So far, it is only the northern branch which has heen studied by the experts.



[*After Wuest*

Fig. 137. Gulf Stream

(The dotted part shows the part of the ocean where the watar is 2° to 4°C warmer than the surrounding water. The tinted part to the left of the dotted portion shows where cool and warm waters mix.)

The presence of the Gulf Stream in the North Atlantic is clearly indicated by the warmer temperatures in comparison to the local temperatures. Fig. 137 shows the main hranch of the Gulf Stream and the temperature anomalies. These anomalies are greater in winter than in summer. For example, there may be a contrast of 20° to 30°F. between the Gulf Stream water and the local water in late winter, while in summer the contrast, on an average, is only about 6°F. It is due to these temperature anomalies that the Gulf Stream has such a fundamental influence on the winter climate of western Europe.

From the Arctic the compensating cool currents for the warm Gulf Stream are the *Labrador current* flowing to the west of Greenland and the *Greenland current* flowing to the east of Greenland.

Nowhere is the effect of winds on ocean currents more marked than in the seas around India. Here the direction of the ocean currents changes with the change in the seasonal winds. The following diagram shows this change :—

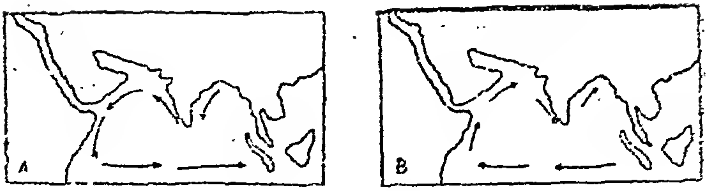



Fig. 138. Currents in India Waters
(A shows currents in winter Monsoons and B shows currents in summer Monsoons)

## Tides

It is the experience of all people who live near the sea that its waters rise and fall twice each day. The rising water is called the 'flood tide' and the falling water, the 'ebb tide'.

The theoretical explanation of the tides is to be found in the force of gravitation from the moon and the sun to which the earth and the mobile water on its surface are subject. The tide producing attraction is produced more by the moon than by the sun. This is because the moon, even though much smaller than the sun, is much nearer to us than the sun is. The greatest distance that separates the moon from the earth is about $2\frac{1}{2}$ lakh miles; while the greatest distance separating the earth and the sun is about 93 million miles—or the moon is about 372 times nearer than the sun. This nearness places the moon in a controlling position in making tides on the earth. For the law of gravitation propounded by Newton, says, that the *attraction varies inversely with the square of the distance.* According to this law the moon's power of producing tides on the earth is $2\frac{1}{4}$ times greater than that of the sun.

The attractive force of the moon and the sun acts on the centre of the earth and thus pulls the whole earth, because it is solid and rigid as one particle. It also pulls the water on the earth's surface facing the moon and the sun at the time. The water particles being mobile, they are pulled towards the sun or the moon independently of the earth. The attractive force expresses itself, thus, in two ways; in pulling the rigid earth as a whole, and pulling the water independently of the earth.

The direct pull of the moon and the sun on the ocean water facing them heaps the water in a mound. This mound is the initial development of the *direct high tide.*

But the earth as a whole is also being pulled, though it cannot be pulled as much as the less rigid or mobile water which is nearer to the attracting bodies than the centre of the earth. The result of this pulling is that the surface of the earth on the opposite side is pulled

away from the water which covers it. The water thus left behind also heaps itself in a mound like the water facing the attracting bodies. It must be remembered that this water, on the opposite side, does not receive the attractive pull to the extent the centre of the earth receives. For the centre of the earth is about 4,000 miles (radius of the earth) nearer to the attracting bodies than this water. This produces a second high water at the same time, the *indirect high tide*.

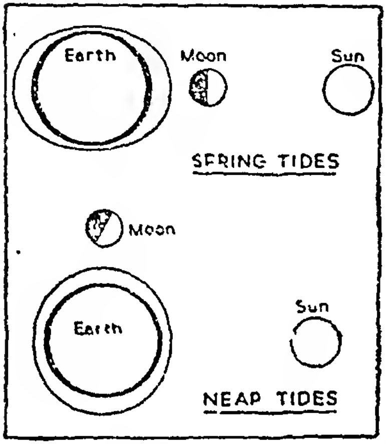



Fig. 139

Thus, there are two high tides produced at the same time on opposite sides of the earth's surface, These tides move round the earth, owing to its rotation. As has been seen in a previous chapter, the time of occurrence of these tides is later and later every day, so that every point on the coast is visited, theoretically, by high water every 12 hours and 26 minutes.

The height to which the water will rise depends upon the degree of combination between the tide attracting forces of the moon and the sun. When the sun and the moon are in one line, the tide produced is higher than when they are at right angles. In the former case the tide is called *spring tide*, and in the latter case, *neap tide*. The first occurs at the time of the new moon and the second at the time of the quarters of the moon.

The above is only the theoretical explanation of tides. Actual observation of the tides, however, reveals that *high water does not occur when the moon is directly overhead.* In fact, high water occurs at all times during the passage of the moon over the meridians. It will be realised that when the moon is directly overhead it only reduces the pull of the earth on the water at that point. Its upward pull actually has no influence on the tide; for the moon does not have a greater pull than the earth itself.

The pull of the moon is, however, partly vertical and partly horizontal. The horizontal pull is more effective. For while it requires a very great force to lift the water vertically away from the earth, owing to the great mobility of water even a slight horizontal pull can heap the water in a high tide. It is, therefore, the *horizontal attraction of the moon that produces tides.* For about 6 hours, from

the time the moon rises to the time it attains the highest position in the sky, this horizontal pull is directed to east and forces the water in that direction. During the next 6 hours, *i.e.*, up to the time the moon sets, the horizontal force is directed towards the west and pulls the water in that direction.

Thus, in 24 hours and 52 minutes, which the moon requires for its daily revolution around the earth, there are the rhythmic movements of ocean water towards land and then towards the sea after every 6 hours 13 minutes. The movement towards land is the *flood tide* and the movement away from land is the *ebb tide.*

We must note that the tide producing forces are of astronomical origin, but the tide as produced by them is fundamentally modified by terrestrial features. The actual rise and fall of water on the coast, therefore, depend largely on local features.

As the tides have a great importance for the movement of shipping, tide tables giving the actual time of the tides for each day are published by the governments. On the basis of these co-tidal maps have been made for certain areas.

There is scarcely any phase of shore life upon which the tide does not leave its mark. Re-modelling of coastlines, builder of salt marshes, a locative factor for harbours and ports, favourable or adverse element in navigation is the tide.

The tides of the world are subjected to the periodicity of the tide producing forces of moon and sun and, therefore, undergo manifold periodic changes in intensity while running through certain cycles as conditioned by the motions and changing distances of the three involved bodies. These variations are different from the variations that are caused by the locality where they occur.

A tide with high water occurring approximately every 12 hours is termed a 'semi-diurnal tide', one with high water every 24 hours is a 'diurnal tide',* and those having a higher high water every 12 hours and a lower high water occurring between any two higher high waters suggesting an interference of two oscillations of waves are 'Mixed tides'.

The 'semi-diurnal' type of tide is associated with the Atlantic ocean, both north and south, and the mixed type with the entire Pacific rim. The diurnal type stands out as a feature of the American and Australasian Mediterranean and of similar enclosed seas. The simple conclusion is that the tide type is related to, or rather is a function of, the type of the ocean basin.

*Bauer, Geo. Review, 1933.

## Various theories of tides

(i) *Progressive Wave or Southern Ocean Theory.* This theory considers the tides of th world as due primarily to the action of the tidal forces of moon and sun on the broad and deep waters of the Southern Ocean, the belt of water that completely encircles the earth south of the great land masses. Here the tidal forces have almost uninterrupted sway, and here these forces raise two tidal waves 180° apart in longitude, which travel from east to west. As each of these waves sweeps past the Cape of Good Hope it generates a wave which travels up the Atlantic Ocean, and it is this secondary wave generated by the primary wave of the Southern Ocean which determines the tides on the shores washed by the Atlantic.

It is important to note the distinction between the primary tidal wave and the secondary wave which sweeps up the Atlantic. The secondary wave travels freely, according to depth. But the primary tidal wave in the Southern Ocean keeps step with moon; it travels not as a 'free' wave, but as a 'forced' wave, compelled by the moon to keep in time with its own movement.

*Stationary Wave Theory.* A body of water is capable of sustaining two different types of wave movement. A wave movement can be formed by raising and then immediately lowering one end of a tank of water. The water will now no longer progress from one end to the other, but will oscillate or swash about an axis in the middle of the tank, so that it will be high water for half of the tank at the same instant that it is low water in the other half. This type wave is known as the 'stationary wave'. At the beginning of the century the Stationary Wave Theory was made the basis of a full-fledged theory of the tide. Harris' theory* is that the tide in the open sea is brought about by stationary wave movements of various oceanic areas which he denominates as 'oscillating system', these systems having free periods of oscillation which are approximately the same as the periods of the tide-producing forces.

According to Harris' theory of Stationary Wave there must be a point of 'no tide'. Such points he calls 'amphidromic points' from which co-tidal lines radiate.

Starting from the consideration that the Atlantic and the Arctic oceans constitute an enormous canal open only at its southern end—since in comparison, the narrow and shallow Bering Strait may be disregarded—Default studied mathematically the various oscillations which such a canal can sustain and the relative importance of these various oscillations in bringing about the actual tide. He found that it is the north-and-south stationary wave oscillation that determines the tide in the Atlantic Ocean.

*Geographical Review, 1928, p. 137.

## Coastline

The importance of the tide depends to a large extent on the type of the coastline which the sea shore meets. In indented coasts having a number of bays and inlets, the tide rises higher than on regular coasts where the tide water is not so marked. We have noted in a previous chapter that the character of the coasts depends on whether the shoreline is submerging or emerging. The submerging shoreline results when either the land is depressed or the sea-water rises. The characteristics of the coast produced by submerging shoreline are a large number of indentations, with numerous bays, inlets, promontories and islands. When pre-existing river valleys are drowned due to submergence the coast is called *ria coast.* When, on the other hand, glacier-cut valleys and troughs are drowned the coast is called a *fiord coast.* The coastline developed by emergence is relatively straight, with few indentations or promontories.

The coastline is due primarily to the work being done by waves and currents which tend to straighten it by cutting away the promontories and filling up the inlets. This work is modified, now and then, by the changing sea-level, and by streams and glaciers.

The following pictures Figs. 140 and 141 bring out the contrast between the ria and fiord coasts :—

[*From Supan.*

Fig. 140. Ria Coast.

[From Supan.

Fig. 141. Fiord Coast:

## ✓ Underground Water

The rain that falls on the surface of the earth is taken partly by rivers and lakes, partly evaporates and another part sinks underground. The sinking* water fills the pore spaces between the rock particles and saturates a certain part of the rock strata. The rocks of the earth's crust fall into two classes on the basis of their capacity to absorb moisture, *porous* rocks and *impervious* rocks. Water fills the porous rocks only; the impervious rocks do not admit water into them. The sinking of the water downward is checked as soon as it comes across a layer of impervious rocks. All the water that sinks, therefore, remains confined to the porous rock. The upper limit to which the sinking water fills the porous rock is called the *water table* which indicates the depth below the ground where the water that has sunk underground can be met with.

In the porous rock the sinking water passes not only downward, but also sideways. This horizontal movement of the underground water follows the slope of the porous rocks. This gives us the impression that there are 'underground rivers' as well as 'ground rivers' on the earth's surface. The waters of these underground rivers rise and fall according to the rise and slope of the porous rock.

*The sinking water is called 'Vadose water'. Connate water is the name given to water entrapped underground during folding; juvenile water is the name given to the connate water when it is brought to the surface volcanic steam.

The water table is, therefore, a zigzag line and not a regular straight line below the surface. As the source of the underground water lies mostly in the rainfall that occurs on the surface, the fluctuations that occur now and then in the rainfall cause similar fluctuations in the underground water table as well. In dry years or periods the water table falls as the supply of sinking water is stopped. In wet periods, the supply of sinking water is augmented and the water table, therefore, rises.

In general, the water table follows the contour of the surface but without the smaller irregularities. It rises, therefore, under the hills and falls under the valleys ; though it is farther below the surface under a hill, because of the mountain mass, than under a valley.

Deeper wells are common in the river valley than away from it.

Where the water table reaches the surface of the ground, water comes out and may form a marsh, a spring or a lake.

The water that fills the porous rocks in any area is not necessarily derived from the rainfall of that area. Underground water travels for hundreds of miles.

The origin of springs depends upon the geological structure of a region. A porous rock must be underlain with an impervious rock and the water table must rise to the surface. In Fig. 142 the origin of a spring is illustrated.

In the same diagram the dotted area shows the layer of a porous rock, say sandstone ; and the tinted area the layer of an impervious rock, say shale. The arrow on top shows the water that sinks underground. This water saturates the porous rock up to the limit indicated by the continuous line marked 'water table 1'. This is the permanent

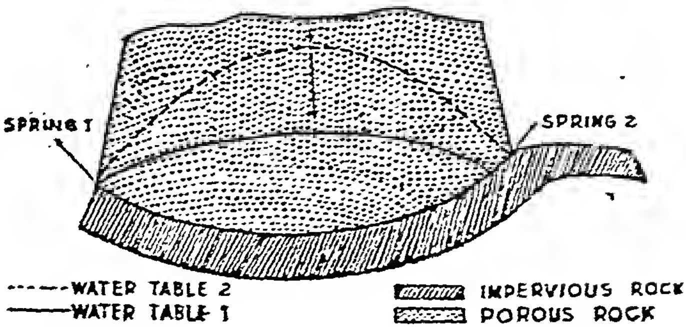



Fig. 142. Origin of Springs.

water table. During the rainy season when more water sinks underground, the water table rises to the broken line marked W. T. 2. To

the left of the figure where the junction between the porous and the impervious rocks takes place, both the lines showing the water table are touching the surface. A spring is, therefore, formed. This spring is marked by an arrow, and will flow both during the wet and the dry season. To the right of the figure, the water table touches the surface only during the rainy season. A spring is formed which flows only during the rainy season. Such a spring is called the 'intermittent spring'. The life of the springs, thus, depends upon the water table. If particularly dry periods occur, even the permanent springs may dry up.

It must be noted that the water table is dome-shaped where the springs occur. The water table falls near the springs owing to the flow of water.

Where the porous rock lies buried under another layer of impervious rock, the water table can reach the surface only when this impervious rock is cut through. The water will rise into this hole to the extent of the pressure that may be exerted by the confined water in the porous rock. If the pressure is very great, the water will rise through the hole to the surface. This kind of hole is called an *artesian well*. In 'ordinary wells' and 'spring wells' water has to be lifted by artificial means. In the following diagram the geological structure that favours the digging of artesian and other wells is illustrated :—

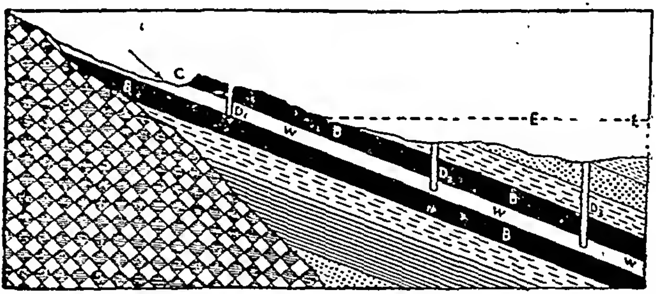



Fig. 143. Artesian and other Wells.

In the diagram above, B shows the impervious rock and W, the porous rock which is trapped between two layers of impervious rock. The arrow shows the place where the water sinks underground. $D_1$, $D_2$ and $D_3$ show the position respectively of ordinary well, spring well and artesian well.

The effect of folding and faulting is considerable on the water table. Folds not only localise a considerable part of the porous rock and thereby increase the amount of underground water that may be

available, but they also facilitate its exposing on the surface. The raised parts of the folds through the denudation of their slopes very often cause springs by the breaking of the cover of the impervious rocks.

Faulting of strata also sometimes exposes the saturated porous rocks on the surface. Springs are thus formed.

Due to folding and faulting there are many opportunities for springs to form in the mountainous areas than in the plains. Besides, in many mountainous regions the rainfall is heavy and the supplies to the underground water considerable. The area of saturated zone is, therefore, very large in these regions.

## Lakes

The lakes are temporary for permanent deposits of water in hollows or basins created on the earth's surface by earth movements (which create faults or depress the land surface in certain areas) or by damming up the drainage basins. This gives us three kinds of lakes :—

(1) Lakes filling the depressions on the earth's surface. Such lakes occur in mountainous areas. The lakes filling the craters of volcanoes and faults may also be classed under these lakes.

(2) Lakes filling the valleys whose outlet has been closed. Such lakes generally occur in glaciated areas where the deposit of moraines has dammed the outlet of the valley. Sometimes, artificial dams have been constructed across rivers to dam up their flow and lakes have thus been formed for developing water power. The greatest example in India is that of the Andhra Lake which has been formed by building a dam across the Andhra River on the Western Ghats near Poona.

(3) Lakes that have been formed by cutting off of a part of a larger body of water owing to deposition of silt. Such lakes are the ox-bow lakes formed by the cutting off of a river meander and salt lakes formed by enclosing a part of a lagoon by sand dunes and off-shore bars. The Chilka lake on the east coast of India is an example of such a lake.

(4) The largest lakes of the world are, however, those which have been formed by glacial action and by earth movements giving rise to faults. The great lakes in the eastern part of Africa are due to the faulting of the earth's crust. Some of the Alpine lakes and the Great Lakes of North America are generally due to glacial atcivity. The following table gives some of the biggest lakes of the world :—

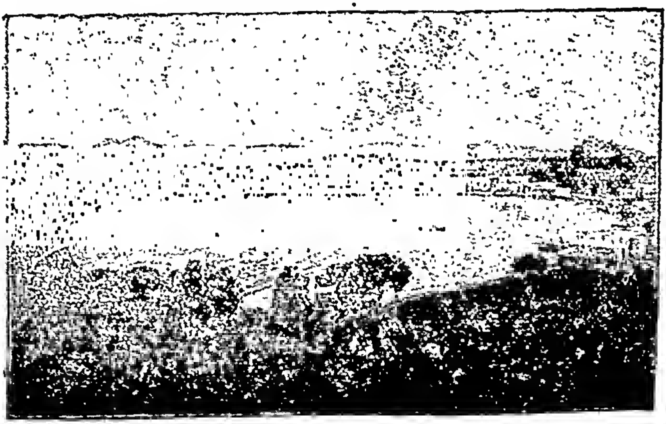
## Biggest Lakes

| Lake | | Area (sq. miles) | Greatest depth (feet) |
|---|---|---|---|
| Caspian | ... | 169,000 | 3,200 |
| Lake Superior | ... | 31,200 | 1.008 |
| Aral | ... | 26,900 | 1,200 |
| Victoria Nyanza | ... | 26,000 | 240 |
| Michigan | ... | 22,500 | 870 |
| Huron | ... | .2,232 | 750 |
| Nyassa | ... | 14,000 | 2,300 |
| Tanganyika | ... | 12,650 | 4,188 |
| Baikal | ... | 12,500 | 4,997 |

The lakes must be regarded as temporary forms of hydrosphere which will be silted up sooner or later. There is a considerable amount of silt that comes to the lakes as rain wash from the surrounding area and as sediment load of the rivers that drain into the lakes. This silt tends to make the lakes shallower and shallower.

The level of the water in the lakes generally fluctuates from the wet to the dry season. During the wet season more water is brought to the river than can evaporate. This raises the lake level. During the dry season evaporation is more marked, and the level, therefore, falls.

The following picture shows a crater lake :—



[*From Supan*

Fig. 144. A Crater Lake.

CHAPTER XV

# BIOSPHERE

ORGANIC AND INORGANIC LIFE—PLANT LIFE—FORESTS—TYPES—GRASSLANDS—TYPES OF GRASSLANDS—ANIMAL LIFE—HUMAN LIFE—RACES OF MAN.

Biosphere is also, like other 'sphere' discussed in this book, a component part of the earth. It includes all forms of *organic life* which need *food* for continuing their life. From the lowliest of insects to the highest form of life, man, is included within Biosphere. The different forms or bodies through which organic life expresses itself have evolved through the ages as a result of the environment. Changing environment has wrought changes in the *form* of life that has appeared on this planet ever since the beginning of time. Fossils provide the evidence to support this statement. We get fossils of plants, animals and even of man. Scientists have established, in many cases, a connection between these fossils and the present forms of life. The difference in the forms is accounted for generally by the climatic changes which we noticed in a previous chapter.

Organic life differs from the inorganic life in its need for food. Rocks do not require any 'food' for the continuance of their existence on the earth. Organic life, *i. e.*, plants and animals, etc., on the other hand cannot continue their existence without food. The chief food that the organic life requires is 'carbon' which gives heat and thus maintains life. The original source of carbon is the atmosphere. It is from the atmosphere directly that the plants and other forms of vegetable life take the carbon they require. The animals get their carbon from the vegetables and not directly from the atmosphere. Animals may also get the carbon they need from other animals which have taken it from the vegetable matter.

Water and oxygen are also needed by organic life for their continuance. These are also derived ultimately from the atmosphere.

When the organic life does not have the necessary amount of the 'food' it requires or it cannot assimilate it due to some defects that have developed in its machinery, 'death' ensues. The form or the body of the organic life functions no more then in the way it used to function. It, therefore, disintegrates and the matter belonging originally to the atmosphere is returned to it. That is how the 'cycle of life' between the atmosphere and the organic forms is completed.

Biosphere, or the organic life, is divided into three classes based

mainly on the degree of the freedom of movement and the possession of some specially developed organ :—

(*i*) Plant life, (*ii*) animal life, (*iii*) human life.

The plant differs from the animal or man in that it has no freedom of movement. It is fixed by its roots to the ground where it was born. Man differs from the animal in having a specially developed 'intellect.'

None of these forms of life are confined permanently to any one region or locality. They spread from one place to the other on the earth's surface. In the case of animals and man it is easy to see how they can spread from one area to the other. They have their organs of locomotion to take them 'alive' from one place to the other. But in the case of plants, their seeds are carried by winds, water, birds or man from one region to the other. The seeds germinate in the new region, if the environment is favourable. In this way, even the plant life spreads.

## Plant Life

Vegetation, of some sort or the other, is the natural covering of the land surface of the earth. Even the so-called deserts have their vegetation, though it may be scanty and inconspicuous.

The distribution of plant life over the earth's surface is determined by a number of factors :—

(*i*) the amount of heat,
(*ii*) the amount and distribution of precipitation,
(*iii*) the nature and strength of winds,
(*iv*) the amount of light, and
(*v*) the character of soil.

Of these, the temperature would appear to play the dominant part. It is, for this reason, that, generally speaking, the main vegetation belts of the earth have a latitudinal or horizontal distribution.

Next in importance to temperature is the amount and the seasonal distribution of precipitation, either in the form of rain or snow. The precipitation determines the type of vegetation a place has. In regions of equal temperature, forests will, in general, occupy the areas of highest precipitation, deserts the areas of lowest precipitation and grasslands the areas of intermediate precipitation.

Apart from the function of winds in helping the plants in transpiration, their baneful effect on tree-growth is well known. Prof. Brockman* has pointed out that the actual tree limit is depressed in

*Quoted by Salisbury in *Geographical Distribution of Plants*, Geographical Journal, 1926.

the regions possessing an oceanic climate, where naturally the velocity of winds is great. The tree limit attains its maximum polar extension in the continental area. In Siberia, for instance, the tree limit attains 72°40′ N. latitude, whilst in the Aleutian Islands it only attains 50° N.

Light is the chief factor whereby plant manufactures its food (sugar) from the green material in the leaves. The longer duration of light to some extent compensates for the short growing season. In Finland and the north of Norway, barley ripens in 89 days from the date of sowing, while in Sweden, at 55° N. it requires 100 days.*

The moisture supply to the roots of the plant is determined by the texture of the soil. The efficiency of a particular rainfall may be greatly influenced by soil structure. So, too, the facility for percolation in hot climates greatly modifies the effect of rainfall. Besides regulating the supply of moisture for the plant, the soil also determines the main part of its food supply.

There are three main divisions of the vegetation of the earth :—

(1) Forests, (2) grasslands, and (3) desert.

These divisions are the outcome of rainfall conditions mostly.

## 1. Forests

Forests grow in area o abundant precipitation. They can maintain themselves even in areas of relatively low rainfall, provided this is distributed with sufficient uniformity. In considering the availability of moisture to the plants, the nature of soil and the amount of transpiration must also be taken into account.

There are three types of forests :—

(*i*) The broad-leaved evergreen forests,

(*ii*) the deciduous forests, and

(*iii*) the coniferous ever-green forests.

The distribution of these types is fairly definitely related to the length of the vegetative season or the period free from frosts.

These types are connected with the tropical, sub-tropical, and temperate regions respectively.

(*i*) *The broad-leaved Evergreen trees* occur in the tropical lowland forests, which are characterised by the absence of any season which may limit the growth through low precipitation or low temperature. Growth in these forests is very rapid, though desiccation too, is as rapid, especially on the sunny afternoons. As an example of rapid growth in the tropical regions it may be noted that it has been observed that three feet of bamboo grew in five days.

*Andrews, *Text-Book of Geography*, p. 68.

The true ttopical 'rain forest' is only found in the regions of gteat rainfall. Where the rainfall is less, or there is not enough available moisture in the ground, or whete the rainfall is with seasonal drought, the tropical rain forest passes into the 'monsoon forest'. Here the underbush withets in dry season and is, therefore, not so dense. The dry season in this part imposes a period of test on vegetative growth similar to the period of rest imposed by cold in tempetate regions. Owing to the intensity of tropical light, the upper parts of the trees are well developed and have a thick covering of leaves. A tropical forest is marked by climbing vines which press upward towards the light. There is no uniform period for shedding leaves in the tropical forest and sometimes blossoms and fruits are found together on the same tree.

The most extensive tropical rain forest, ot *selva*, as it is known there, is found in the Amazon Basin and presents the world's most vigorous vegetation growth. The outstanding peculiarity of this fotest is the extraordinary variety of species of trees. In the ttopical rain forest it is not unusual to find as many as from eighty to a hundred species on an acre of land.

Thete ate many patts of the tropical forest areas which support only a scrub fotest in spite of the fairly high annual rainfall, for the *rainfall effectiveness* in these ateas is relatively low owing to high temperatures resulting in a vety rapid evaporation. These sctub fotests ate sometimes known by the Brazilian word 'Caatinga.'

In the Caatinga, the forest floor is usually grass-covered. There is a definite seasonal rhythm with the rains in these forests. Duting the the rainy season the trees are green with the brilliant flowers, but during the dry season the leaves fall to the ground and the branches are bare. The Caatinga does not possess a great variety of species.

*(ii) Deciduous forests* are found in regions of marked climatic periodicity, whether it be the alternation between summer and winter of the temperate regions, or between dry and wet seasons of the sub-tropical regions. The deciduous trees, by shedding leaves, maintain the balance between water absorption and transpiration. The deciduous trees are, therefore, not confined either to the temperate or to the sub-tropical regions.

Slow tree growth, short stature and the formation of great quantities of wood as reservoirs of plant food during the resting season are some of the characteristics of deciduous forests.

The deciduous forests occupy two distinct ateas in the northern hemisphere, east of the dry interior, roughly between latitudes 40° and 60°. In the southern hemisphere these forests extend from about latitude 25° on the east coast and 40° on the west coast to the extreme south. They are almost absent in Africa and Australia.

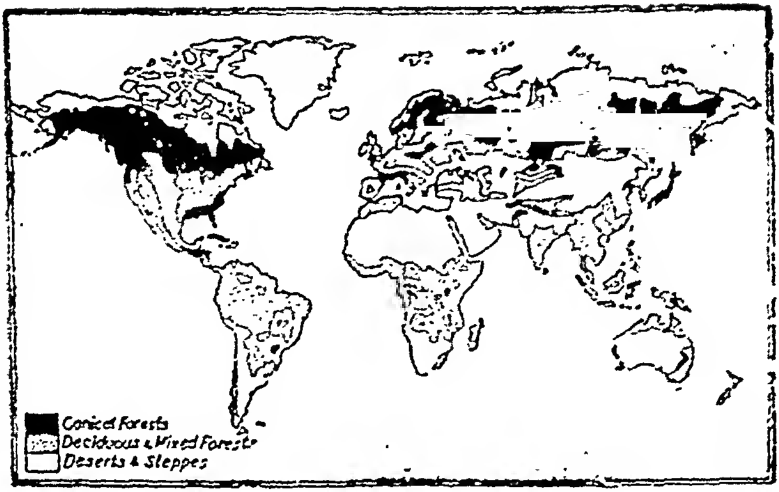



Fig. 145. Types of Vegetation

Mixed with the deciduous forests are found here and there strands of coniferous forests, especially in hilly areas. The deciduous forest belt is, therefore, also known as the belt of 'Mixed forest'.

On the poleward margin of the hot deserts lie, in the Mediterranean regions, broad-leaved, evergreen, scrub forests of unique character. In these regions the winter is not cold enough, or the summer drought long enough, to enforce a period of rest. As a result there is no season when the leaves drop from the trees and growth ceases. The coming of new leaves and the accumulation of reserves take place in the autumn at the beginning of the rainy season. The flowing and reproduction take place in spring at the end of the rainy season. The Mediterranean vegetation thus differs from the Selva, which is also evergreen but in which there is no seasonal rhythm.

Among the various types of plant are scattered and open woodlands of cork-oak, olive, coniferous trees like pine and fir, light growths of deciduous oak and thickets of stunted, prickly evergreens.

The Mediterranean vegetation adapts itself to the summer drought in many ways. The individual trees are widely spaced so that each may tap supplies of water from a large area of ground. On all the plants deep taproots and a wide development of the surface root are characteristic. The woody and fibrous parts are more developed than the foliage. The evaporation from the plants is checked by a thick bark and by the nature of leaves, which are small, thick and stiff, with hard, leathery and shiny surfaces. The botanist calls such leaves, 'sclerophyll'.

Besides the scrub forest, many parts of the Mediterranean lands are covered by a low growth of bushes and shrubs, known as 'Maquis' in Europe, and 'Chaparral' in the U. S. A. The Maquis is composed mostly of the plants which make up the undergrowth of the scrub forest; of dwarf or scrub oak or chestnut. The Maquis is almost worthless, for only goats can graze on the bark and leaves, it being too thick to allow the grasses to grow. During the dry summers this vegetation-cover turns yellowish brown, against which the green oaks *stand out in striking contrast.*

*(iii) Coniferous Forests.* As we pass northwards where the unfavourable cold season is very long, the broad-leaved deciduous forests are replaced by narrow, needle-leaved evergreen conifers. The coniferous forest occupies a continuous belt from east to west in the northern temperate zone, and flourishes on the slopes of mountains of more southern regions also. It is also the predominant type in areas with porous, dry sandy soil, such as the eastern margins of the United States. The wide extension of this type is due to its capacity for standing climates where the cold winter makes protection against excessive transpiration necessary due to very dry winds. The everlasting, small and needle-shaped leaves of the conifers are best adapted to avoid transpiration.

The conifers grow much better in regions of milder climate. But it is only in the north that they are freed from the serious competitions of broad-leaf species.

These forests are known as 'Boreal forests' or 'Taiga'. They can be contrasted almost in every respect with the tropical Selvas. No doubt, they are both evergreen conifers and do not enjoy the year-round growing season of the Selva.

Spruce, fir, larch and pine are the chief coniferous trees, and these are sometimes found growing with such broad-leaf trees as aspen, birch, beech, maple and willow. These forests, except in northern Manchuria, lie north of the range of the oak.

The coniferous forests are interrupted by broad-leaf growths along river banks or in some of the swampy areas. The density of growth varies from place to place, but nowhere can it compare with the Selva. The poor, stunted and knotted trees of the Taiga are of little value for timber.

The floor of these forests in many parts is littered with fallen trees which, because of the high pitch content of the wood and because of the cool climate, decay very slowly. The pitch content of the conifer renders it peculiarly liable to catch fire. In dry weather, fires start very quickly. There are few areas in which charred trunks do not give evidence of forest fires.

The clearings in these forests, whether made by extensive cutting or by fire, do not fill up rapidly as is the case in the Selva, by the return of original species. At first, only low bushes appear. Then, instead of conifers, the first trees to gain a foothold are broad-leaf types, chiefly birch and aspen. Only after a long time do the original species appear and reproduce the forest.

The coniferous forests extend almost uninterruptedly over North America and Eurasia. The southern boundary of these forests in the northern hemisphere descends progressively from east to west. In the east of North America their southern limit is reached about 45° N.; in Asia about 55° N.; and in North-west Europe about 60° N.

In Alaska and the Mackenzie basin, the coniferous belt extends 300 miles north of the Arctic circle; in the east of Canada it ends 500 miles south of it, owing probably to the reduction of the summer temperature by the great frozen northern area.

## 2. Grasslands

Where effective or available moisture is small, the prevailing type of vegetation is grassland. There are three chief types of grassland: (*i*) 'Steppes' and (*ii*) 'Prairies' in the middle latitudes, and (*iii*) 'Savanna' in the low latitudes.

(*i*) *Steppes.* The distinction between these is quite marked and depends on climatic conditions. The steppes are grasslands of the cool, semi-arid regions. They are covered by a continuous mat of grasses which are at maturity only a few inches in height, although in unusually wet years taller grasses give the vegetation over an uneven appearance. The short grasses here are developed in areas deficient in moisture. After a rain they spring quickly into activity and then again become parched and brownish until the next shower. The water is absorbed by the surface layers of the soil only, and underneath them the layers are permanently dry. It is the presence of this surface moisture that makes possible the growth of the shallow-rooted short grasses. The largest stretches of steppes are found in Eurasia extending from the Black Sea eastward beyond Lake Balkhash, including the great Kirghiz steppe; two small patches in the Far East, in Manchukuo formerly Manchuria and the Ordos desert; and in North Africa, where there is room only for a narrow band of steppe between the desert and the mountains or the Mediterranean shore. In North America, the Great Plains and in South America, along the eastern piedmont of the mountains in Patagonia are steppelands.

(*ii*) *Prairies.* Unlike the steppes, the prairies have tall and deep-rooted grasses. At maturity these grasses reach heights of three to ten feet or more. Around most of the prairies the edge of the forest is sharply defined. Except for the forests along the streams, the prairies themselves are entirely treeless in their natural condition. The prairies

are limited by a fairly definite moisture supply towards the steppes. Where the soil moisture extends to as much as two feet below the surface, the prairies gain a foothold at the expense of steppes. Tall grasses penetrate well within the areas generally deficient in moisture on sandy soils, but short steppe grasses are found on clay soils well within the humid lands. The most extensive prairies occur in North America and in South America (here known as the Pampas).

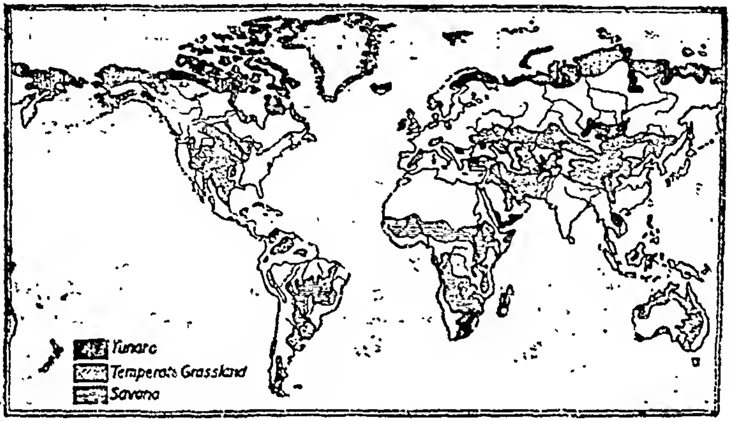



Fig. 146. Types of Grasslands.

(*iii*) *Savanna.* The drier parts of the low latitudes are occupied by a zone in which forests and grasslands intermingle. This zone is the savanna. Essentially it is the transition between the forest and the desert. The savanna vegetation includes enough scattered trees and is thus distinct from the prairies or steppes where trees occur only along streams. The savannas themselves can be divided into a number of types reflecting transition from wet to dry conditions.

The savannas include the parklands of Africa (Sudan, East African Highlands, and around the Kalahari as far south as Natal), the Venezuelan *llanos*, the Brazilian *campos*, and the Australian *downs*. They also occupy the drier parts of India, Central America and East Indies.

### 3. Desert Vegetation

There are two kinds of deserts, the hot deserts and cold deserts. Both of these have a very scanty vegetation. In the case of hot deserts, cactus and bulbous vegetation is typical; while in the Tundra or the cold desert mosses and lichens are the prevailing types. In one case, the limiting factor is scantiness of rainfall while in the other, it is the want of sufficient temperature.

The dry, scorching winds of the hot desert cause desiccation and do not allow trees to grow. In the cold desert, the cold Arctic winds do not allow tree growth, not merely by reason of increased transpiration from the plants, but also because the resulting cooling of the soil does not permit the trees to absorb enough moisture through their roots which are in the frozen soil.

Some annuals, mostly grasses, have a hasty life in these deserts as soon as conditions warrant it. In the hot deserts, very high grasses develop immediately after a good shower. In the cold desert, the summer marks the beginning of life of many grasses and flowering shrubs.

## Animal Life

The animal life on the surface of the land depends directly or indirectly, upon this vegetation. Different types of animals are associated with different types of vegetation.

The wealth of vegetation in the equatorial and monsoon rain forests has caused a rich development of bird, insect and animal life. The luxuriance of tropical undergrowth crowds out the larger ground animals; only the elephant with its huge body is able to force its path through this forest. Where the forest is more open, as in the lands of tropical summer rains, the number of ground animals increases.

In the coniferous forests, there are two broad groups of animals; those which are structurally adapted for forest life, and those which roam over the prairies and the steppes but visit the forests for shelter or food. Among the former, the squirrel and among the latter deer, wolf and fox are important. In the deciduous forests the animal life is similar to that of the coniferous forests.

The animals of grasslands and scrublands are generally grass-eating. Like desert animals, those of the savanna can go for a long time without water, but they drink deeply when they reach it. The long neck and the forelegs of the giraffe enable him to browse upon the leaves of the trees which rise above the grasses.

The larger animals of the temperate zone, to secure food, migrate northward or up the mountains in summer, southwards or down to the sheltered valleys in winter. In the tropics the movement is away from or towards the equator with the swing of the rainfall belt, or towards the river valleys and water ponds as the dry weather advances.

Owing to the settlement of the temperate grassland, the larger wild animals are becoming extinct. The bison of North America is an example.

Like vegetation, the animal life in the deserts is scanty. In hot deserts the animals conserve water by being non-perspiring. In the Tundra, the animal life is mostly migratory.

## Human Life

Man knows a good deal about the evolution of plant life and about the evolution of animal life, but, paradoxical as it may seem, he knows very little about his own evolution. Human fossils have been rare, and the few that have been found in some parts do not give much clue to the man's past. It is, however, certain that man has evolved from some low creature.

The first fossil that can be connected with man in some way is known as the *Ape Man of Java*. It was discovered in Java in 1892 and seems to be intermediate between ape and man. The brain capacity of this fossil definitely relates it to man rather than to the ape. There are, however, so many uncertainties about the rest of the fossil that it does not help to solve the problem of the descent of man.

In 1907, another fossil consisting of lower jaw was found near Heidelberg in Germany. The teeth in this jaw are very much similar to human teeth. The scientists believe that the *Heidelberg man* occupied a higher stage of evolution than the Ape man of Java. Later, in 1911, a part of a skull was found in Piltdown in England. Near it, though not with it, were also found a tooth and some bone fragments. This find is described as the *Piltdown man*.

In 1928, remains of a more advanced man were found near Peking in China. These are known as *Peking man*. The scientists have not yet decided whether the Peking man occupied a higher or a lower stage than the Heidelberg man, though they are agreed that it is more advanced than the Ape man of Java. We are, therefore, uncertain of our own ancestry!

The world is inhabited today by different *races of man*. These races differ from one another in features and character. These differences must have evolved as a result of the differing response to the natural environment in which they found themselves. One may conclude from this, therefore, that all races of man originally came from the same stock. The original stock may have been in Central Asia or Western Europe.

The development of man on this earth has been characterised by a widespread migration. This migration has been more widespread than the migration of animals or plants. For man, with his specially developed intellect, has been able to circumvent all barriers and has adapted himself to all climates.

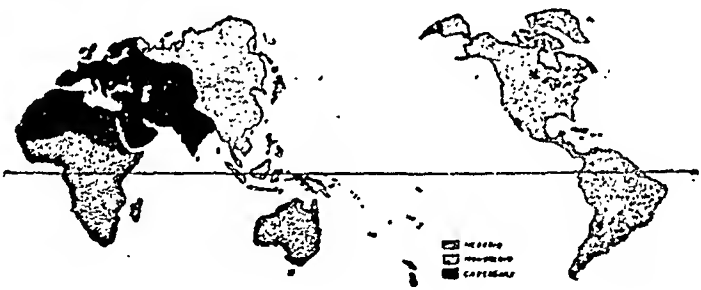
The races of man have been classified on several bases—colour, stature, features and hair, etc. The simplest classification is based on colour—white, black and yellow.

These three primary classes of the races of man are generally described as Caucasian, Negroid and Mongoloid. It must be remembered that the colour associated with these classes is only used as a

convenient label and has no descriptive value. For there are millions of Caucasians who have a darker complexion than Mongoloids. Each of these primary races are sub-divided into natural sub-divisions which are as follows :—

| | |
|---|---|
| Caucasian | 1. Nordic, |
| | 2. Alpine, |
| | 3. Mediterranean, |
| | 4. Aryan. |
| Negroid | 1. African Negro, |
| | 2. Oceanic Melanesian, |
| | 3. Negritos (Dwarfs). |
| Mongoloid | 1. Mongolian, |
| | 2. Malaysian. |
| | 3. American Indian. |

The following diagram shows the outline distribution of major races of man :—



[*After Kroeber.*

Fig. 147. Races of Man.

The migrations of races from one area to the other must have been due to the search for food and for protection. The various ice ages occurring during the recent geological time must have forced a large-scale migration of peoples from the areas of Central Asia and Europe which were among the most important areas invaded by glaciation.

Owing to the development of scientific knowledge and the consequent development of communications, there has been a greater and greater mingling of different races of the world today. It is, therefore, difficult now to fix definite boundaries to the geographical distribution of the various races of man.

# APPENDIX

## DEVELOPMENT OF GEOGRAPHY

The desire to know something about his surroundings is inborn in man. In the primitive man this desire is confined to know the directions of some of the objects in his immediate vicinity which help in satisfying his wants. Later, as the primitive man becomes civilized, he observes the various natural phenomena and their working on the surface of the earth. He also tries to know the geographical distribution of the phenomena and their causes. It is by such a knowledge that he brings about an adjustment between his powers and the natural environment which ultimately results in his further progress. The large-scale migrations which have marked the human history in the past imply some kind of geographical knowledge. To prove that such a knowledge did exist are the legendary tales and mythology common to all peoples in the world. It is true that very soon this geographical knowledge became worse than useless, because in being passed on by the word of mouth by the original observer through a number of intermediaries a considerable amount of exaggeration was introduced.

The systematic development of the study of geography is due, however, to the Greeks. About 2000 B. C. the Greek legends and poetry began to incorporate descriptions of lands lying near the Aegean Sea. Sometimes descriptions were also given of lands far off from the Aegean Sea. Thus, Homer, the Greek poet, describes in his book Odyssey the land of the Laestrygons and of the Cimmerians which, according to the account given in the book, must have been somewhere near the Arctic Circle in Europe.

Almost from the beginning of its development, geography was allied with philosophy in Greece. Greek philosophers began to philosophise about the natural phenomena that they observed. Thales of Miletus (640-546 B. C.) who is regarded as one of the founders of Greek philosophy was a leader of this new thought. He was not only a philosopher but, which seldom happens, also a businessman who often travelled to Egypt in connection with his business. These travels provided him with considerable geographical knowledge which he imparted to his disciples. Among his disciples was Anaximander who continued the work of his teacher and is supposed to have made the first map of the world.

The great philosophers originally believed that the earth was the floor of a casket covered by a dome which was the sky and whose foundations lay beyond the ocean. Later, they came to believe that the earth was a flat dish which was floating on the ocean.

It was the Pythagorian school of philosophy which was the first to give to the world the idea of a spherical world revolving around a centre. The credit of this idea should not go to Pythagoras but to one of his pupils, Philalaus. This idea, however, did not find a wide acceptance then. It was reserved for a later period of world history to be thrilled at a restatement of this very idea of the sphericity of the earth.

Most of the work of the early Greek philosophers was concerned with finding out the nature of the universe, or cosmography. From about 500 B. C., however, books on descriptive geography of lands also began to appear. In the absence of a printing press, these books were written by hand. Their circulation was obviously limited. Hecataeus was one of the first such writers. He wrote in 500 B. C. two volumes on Asia and Europe, and gave a sort of map of these lands. Herodotus, who is regarded the 'father of history,' wrote in 484 B. C. a history of Rome and gave in it a considerable amount of geographical description. The production of books on geography was continued with vigour in the Roman times. The Romans, with their far-flung empire, encouraged the writing of books on geography. The most famous author on geography during the Roman times was Strabo (63 B. C.-A. D. 19) who wrote in seventeen volumes a Geographia Generalis, Strabo was Greek by birth but he flourished in Rome.

The geographical work of the Greek philosophers received a great impetus in the victories of Alexander the Great (356-323 B. C.). Alexander founded a new town in Egypt, Alexandria in 331 B.C. It was Alexander's ambition to make this town the greatest centre of learning in the world. He, therefore, founded a big library there and invited a number of famous Greek scholars to work there. Eratosthenes was appointed the Librarian. The centre of geographical learning, therefore, now shifted from Greece to Egypt. Alexander was inspired in his encouragement of learning by his teacher Aristotle who was a pupil of Socrates. Alexander always took with him in his campaigns a number of Greek scholars who added to the geographical knowledge.

The greatest contribution of Alexandria was in the field of Mathematical Geography. Eratosthenes computed theoretically the circumference of the earth in 276 B. C. Hipparchus evolved in 140 B. C., a system of climatic-zones on the basis of the longest day on the parallels of latitude. Thus, the earth was divided into Torrid

and Temperate zones by mathematical calculations and not by actual observations. It was also at Alexandria that Claudius Ptolemy drew his map of the world with a system of latitudes and longitudes. It must, however, be borne in mind that this map was responsible for many false notions about the earth which persisted for a long time. Ptolemy was also responsible for spreading the belief that the sun revolves round the earth (Geocentric system) which is fixed.

The advent of Christianity is Europe practically led to the stoppage of all research directed towards the unfolding of the mystery of the universe. For Christianity preached its own beliefs about the origin of the earth and the universe generally, which were not in agreement with what the Greek philosophers had discovered. It was, however, considered unchristian to hold beliefs contrary to those advocated by the Church. Roman times were, therefore, followed by 'Dark Ages,' in Geographical knowledge. It was not until the Middle Ages when the period of renaissance set in that scientific work was started again. The restarting of scientific work once again put geography on the path of progress.

Even during the so-called 'Dark Ages' for geography, the work was continued in descriptive geography, for the Church did not discourage this kind of work. The rise of Islam about the year 600 A. D. and the various campaigns which the followers of Islam undertook subsequently for the spread of their religion did much to provide material for this branch of geography. The Muslims occupied Jerusalem, the holy place of the Christians in 637 A. D. They also took Egypt in 640 and Spain in 711 A. D. The occupation of Jerusalem by the Muslims led the Christian priests in Europe to organise religious wars, known as Crusades, for the possession of their Holy Land. There were in all seven crusades, organised at different periods beginning from 1096 and ending with 1270 A. D. Even though they failed in their immediate object, the crusades were of tremendous value for the development of geographical knowledge in Europe. The crusaders carried back to their country the knowledge of the lands they had visited in the course of the crusades.

The rise of the Mongol power from the 13th to the 16th century also led to the development of geographical knowledge. At one time the Mongols overran the greater part of Europe and Asia, including India, China and Russia. The practice of exchanging emissaries between different kingdoms was an important means to encourage travel between two countries and thus to spread geographical knowledge.

The knowledge gathered about the various lands visited by travellers or crusaders was often available to the public in the form of itineraries written by experienced travellers. There were a large number of itineraries but they can all be grouped into three broad

classes according to the purpose they had in view. These three classes of itineraries were :—

(*i*) Roman itineraries giving information about Roman countries ;

(*ii*) Mediterranean itineraries also known as Stadiasmus of the Mediterranean giving information about the ports and the distances separating them ;

(*iii*) Jerusalem itineraries giving useful information for travellers to the Christian Holy Land. The information contained in these itineraries was often disappointing. In some cases it was found that the author had drawn upon his imagination rather than the geographical facts he wanted to describe.

The 'Dark Ages' in geography were, however, short-lived. For there arose a movement among certain sections of Christian priests directed towards research about the nature of the material world. This movement was called *scholasticism*. The object was to encourage learning among the monks, who were also trained to study cosmography so that they could understand the biblical references to countries, mountains and rivers, etc. One such place where scholasticism was encouraged was the monastery founded by Cassiodorus (500-560 A. D.) at Viviers.

One of the direct results of scholasticism was that 'Encyclopaedias of knowledge' began to be written, covering almost all branches of learning. Among the first to appear was the 'History of the World' by Orosius, a Spanish priest of the 5th century, A. D. A geographical introduction was included in this book. Another important work of this nature was 'Origins or Etymologiae' by Isidore of Seville who was a bishop during the 7th century, A. D. This book was in twenty volumes ; two of which, the thirteenth and the fourteenth, deal with geography. The revival of learning following the Dark Ages was thus marked by a good deal of geographical literature.

The map being an essential feature of geography, its development proceeded side by side with the production of books on geography. In fact, there is evidence to prove that the map preceded the books on geography. The oldest known map is the Babylonian map* excavated from the ruins of the city of Ga Sur, about 200 miles north of Babylon. This map is engraved on a piece of baked clay. The date of the map is estimated to be 2500 B. C. The foundations of our modern map, however, are based on a system developed by the Greeks. We have noted above that Ptolemy was the first to develop a system of co-ordinates (latitudes and longitudes). His system provided the basis of

*Raisz, *Cartograph*, McGraw Hill.

all maps and charts for several centuries. It was only during the later Middle Ages in Europe that other systems were devised, specially by the Flemish cartographers. Ptolemy's mistakes were realised and his system of co-ordinates was, therefore, given up.

The maps that were in use in Europe until the close of the Middle Ages may be classified as :—

(*a*) Churchmen's maps which showed features of biblical references only and were of no practical use.

(*b*) Portolano charts which showed sailing directions and distances between ports on the Mediterranean.

(*c*) World maps or Mappaemundi.

The portolano charts were fundamentally the graphical representation of the ancient *peripli* which were the written itineraries compiled by sailors in older times. These charts contained no indications of longitude or latitude, but they were covered with a network of sailing routes or loxodromes. These sailing routes proceeded from a number of foci regularly distributed over the chart. The charts showed a very high degree of accuracy for the Mediterranean coast. But for regions outside the Mediterranean they were hopelessly inaccurate. The reason for this was partly the sailor's unfamiliarity with the shores of the open ocean and partly the use of a different scale on which the charts for the Atlantic were drawn.

The portolano charts that exist today are mostly of Italian origin, made at Genoa and Pisa.

The Catalan map, which also is classed with the portolano charts, is not, strictly speaking. a portolano chart : it is really a world map drawn around the portolano chart.

The portolano charts were produced in large numbers in response to the demand arising out of the increased maritime activity from the twelfth century onwards. There is Marco Polo's evidence to prove that the portolano charts were really based on sailing charts made by the Arabs at much earlier period.

The Mappaemundi or the world maps drawn until the Middle Ages were of very little practical significance, in contrast with the portolano charts which were of much use in navigation. The Mappaemundi must be regarded as a piece of decoration rather than as a source of information.

Apart from the Catulan map, mentioned above, the Este world map (about 150 A. D) and the Borgian world map, of about the same date are the two most important specimens of the Mappaemundi that are found today. There are three outstanding features that appear in most of the world maps :—

1. The hold of the Church is conspicuous in all maps which give, therefore, considerable prominence to biblical topics and topography.

2. Speculation about the location of the Terrestrial Paradise mentioned in the Bible led this Paradise being shown in different places in different maps.

3. Harmonising of established facts with existing traditions to fall in line with the teachings of the Church led to deliberate mistakes being made in the map. The practice of harmonising became very popular from the fourteenth century. Harmonising made the cartographer's task more and more difficult as exploration progressed and the traditional facts were definitely disproved. Owing to this harmonising that was attempted by every cartographer in his own way, no two world maps of the fifteenth century give the same world view.

The world maps drawn during the fifteenth century suffer from a tendency to suppress facts, as well. In order to keep a monopoly of exploitation and trade, the Portuguese kings decided to keep secret the discoveries of certain places. New facts about discovery were, therefore, available to the map-maker very long after the actual discovery.

The Age of Discovery that was ushered in by explorers like Columbus, John Cabbot and Vasco da Gama extended the boundary of the known world considerably. Explorer after explorer discovered new lands and new places which enriched the geographer's knowledge. The new facts were being amassed with such speed that few people had time to philosophise about them. They had time only to record them, and thus a type of geography developed which may be called the 'Gazetteer Geography.' The Gazetteer Geography developed in Europe at a time when the colonists were moving to the newly discovered lands to take advantage of their riches. For, almost every traveller who returned from these new lands had some tempting stories to tell about their gold, silver or other deposits. It was, therefore, to serve the needs of the colonists that geographies containing little more than a list of rivers, capes, mountains and in some cases products and towns of several countries were published.

The greatest need of the times, however, was to perfect the art of cartography so that accurate and reliable maps could be produced. The new cartographical work that was undertaken in response to this need can be divided into two parts :—

(1) Correction and augmentation of Ptolemaic records of latitudes and longitudes by careful observation with the help of improved instruments.

(2) Developing new map projections suitable for world maps.

The new work was undertaken in earnest in Germany, Flanders and France. The work in Germany concerned itself mainly with the reproduction of corrected world maps, chiefly under the leadership of Peurbach, Jean Werner and Peter Apian. The work in Flanders is made famous by the development of a new world map projection, the Mercator projection. This projection was developed by Gerhard Kremer (1512-94) who founded at Louvain a geographical establishment for the construction of astronomical instruments, collection of geographical records and preparation of maps.

The map work in France specialised mainly in the preparation of topographical maps of small areas. The results of a trigonometrical survey were first used for topographical mapping of France by Cassini and later by de Lisle. These maps attained a high degree of excellence.

The cartographical work of the period received much help from the work of the French Academy of Paris (founded 1660) the Royal Society of Arts, London (founded in 1662) and the Greenwich Observatory London (founded in 1675). The measurement of the arc of a meridian between Paris and Amiens in France by Jean Beaured was also a help to cartography. The invention of machine printing (1454 by a German named Gutenberg) enabled the production of cheap maps and charts and thus helped in their popularisation.

During the 19th century topographical surveying and the preparation of topographical maps on a large scale was undertaken by the governments of most of the countries of the world, chiefly for military purposes. This made available detailed maps which could be used for interpreting geographical facts in the light of new facts of science. For while new lands and new surface features were being discovered by travellers and surveyors, the scientist was discovering in his laboratory laws of nature which were hitherto unknown. The new laws of nature were applied to interpret the geographical facts, thus giving rise to the 'casual study' in geography. The casual study was the keynote of the development of geography during the second half of the 19th century which witnessed the advent of the genetic interpretation of land forms, or the birth of geomorphology, and the study of the distribution and activities of man as determined by environmental conditions. The casual study of geogr phy later became more critical and recognised the supreme place that man occupies in the adjustment to his environment. That is to say, the study of geography shifted from *determinism* preached by Ratzel in which man played a subordinate role to nature, to *possiblism* in which man is given his rightful place.

Two names stand out prominently in the development of Modern Geography, Alexander von Humboldt and Carl Ritter.

Humboldt was born at Berlin in 1769, and was a great traveller. He published his book 'Casmos' in which were laid the foundations of a systematic regional descr ption, and a comparative study of similar forms and regions on the surface of the earth. Humboldt was, in the main, a physical geographer and tried not only to co-ordinate facts, but also to establish laws accounting for the character and distribution of these facts.

Ritter was born in 1779 near Magdeburg in Germany. He was primarily a historian and his chief object in geography was to show the dependence of the history of mankind on physical environment. His best work was 'Erdkunde' published in 1817. In this book Ritter laid the foundations of the modern human and regional geography.

The modern work in Geography has been considerably influenced by the Geographical Societies; of Paris, founded in 1825, of Berlin, founded in 1827, and of London, founded in 1830. These societies encouraged the advancement of geography in all possible ways. They provided a common platform for the clarification of views; they organised popular lectures for the propagation of new ideas in geography; and they encouraged research and discovery by the award of medals, prizes and financial and other assistance.

Geography has, however, made little progress in India. *Our people are not yet impressed by the value of geography!*

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